A GROUNDWATER MONITORING NETWORK

AND

PARTNERSHIP FOR ONTARIO

SUGGESTED GROUNDWATER MONITORING NETWORKS

FOR TEN BASINS IN SOUTHERN ONTARIO

PREPARED BY

ENVIRONMENTAL MONITORING AND REPORTING BRANCH
MINISTRY OF THE ENVIRONMENT

IN COOPERATION

WITH

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CHAPTER ONE

INTRODUCTION

By

S.N. Singer, C.K. Cheng, G. Soo Chan, and J. Harman

1.1 GENERAL REMARKS

Groundwater is a major source of water supply for agricultural, commercial, industrial and municipal uses, and it is critical for the survival of fish and aquatic life in Ontario's watercourses. Decisions related to the use and management of groundwater are being made every day by various government agencies, conservation authorities, municipalities, and the general public. These decisions range from locating new groundwater supplies to assessing the potential impacts of proposed landfill sites, and from determining the effects of non-point sources of contamination on local aquifers to conducting studies on regional or watershed scales. The instances differ from location to location, but the need for good baseline data about groundwater persists unchanged.

In 1995, a review of existing groundwater monitoring programs within the Ministry of Environment (MOE) was undertaken by the Environmental Monitoring and Reporting Branch. The review, which involved the identification of MOE's monitoring needs and the provision of options on future directions, concluded that most groundwater monitoring in Ontario is being conducted as part of site specific assessments. The review also determined that a network of monitoring wells existed in Ontario between 1946 and 1979. These monitoring wells were used to measure the fluctuations of groundwater levels for detailed hydrogeologic studies as well as for assessing the impacts of water supply withdrawals and the resolution of interference complaints.

The 1995 review affirmed the need for a comprehensive groundwater database for Ontario to characterize the location, quality and sustainable yield of the resource and describe *where*, *how*, and *why* the resource is changing. A groundwater monitoring network strategically distributed throughout the province can provide such a database. The network would provide baseline data on ambient groundwater conditions throughout the province. The data could be used to prepare annual reports on future trends with special attention to existing and potential problems related to quality or quantity. Advisories could also be issued to specific municipalities where groundwater conditions indicate the need for action.

To be effective, the design of the groundwater monitoring network should be flexible and tailored to fit regional hydrogeologic and land use conditions, current and future water demands, and the specific needs of various users. The design should also recognize the dynamic nature of groundwater systems as affected by both natural phenomena and man-induced changes. Further, the success of an informative network will depend on a cooperative partnership among federal and provincial agencies, conservation authorities, municipalities, industry, academia, and the general public. Together these groups can implement mutually beneficial monitoring and data interpretation by sharing resources, identifying opportunities, and sponsoring technology transfer symposia.

1.2 THE PROVINCIAL GROUNDWATER MONITORING INFORMATION SYSTEM

An integral part of the proposed monitoring network is the design of an effective database management system capable of storing, verifying and retrieving information to facilitate interpretation and reporting and give direction to remedial actions. To this end, the data management system should allow users to select the monitoring wells within a geographic area of interest and to examine the information and data associated these wells.

The establishment of the database would involve the synthesis of past data as well as the collection of new data. Data related to local groundwater quality and quantity are available in various forms in both public and private sector databases such as:

- MOE Water Well Information System (WWIS),
- Dinking Water Surveillance Program (DWSP),
- Provincial Water Quality Monitoring Network (PWQMN),
- municipal water supply programs,
- site remediation works (Smithville, Elmira etc.),
- impact assessment studies (development of gravel pits or redevelopment of industrial land),
- Waste Management Master Plans,
- environmental assessments dealing with waste disposal sites,
- Permits to Take Water and Certificates of Approval that are issued to operate water supply wells or waste sites,
- results of bacteriologic and chemical analyses of samples collected from water wells by the Ministry of Health,
- test drilling and well surveys prior to road construction projects conducted by Ontario Ministry of Transportation,
- land development applications to the Ministry of Municipal Affairs and Housing, and
- special studies such as the Ontario Farm Well Survey in 1992.

Data from the above sources will be examined and, when feasible, linked to or incorporated into the proposed groundwater database. To ensure that the necessary baseline data are being collected, a minimum level of monitoring has to be done. This will include the taking of water level readings in monitored wells and the collection of water samples for chemical analyses. A minimum requirement for the identification of water quality will be the determination of conventional chemical parameters and selected metals in all wells. In addition, selected pesticides will be analysed in areas of intensive agriculture and selected volatile organics will be analysed in urban and urban fringe.

Because the water samples will be collected by different partners and submitted to different laboratories for analysis, stringent quality assurance/quality control (QA/QC) protocols will be required for the proposed monitoring program. These protocols will be distributed to all partners in the form of a guidebook to ensure uniformity in sample quality. Further, to reduce data entry and QA/QC requirements, the data will be submitted electronically from the analytical laboratories to MOE.

1.3 SELECTED AREAS FOR GROUNDWATER MONITORING

Because the majority of Ontario's population lives in its southern parts where more than 90 percent of the water wells are located, it is logical to begin the implementation of the groundwater monitoring network in southern Ontario. Toward this end, nine basins and one area south of Georgian Bay (the Severn Sound drainage area) were selected to implement the initial phase of the monitoring network. If required, additional areas can be added to the network in the future. The selected areas for monitoring are:

S Big Otter Creek drainage basin,
S Bowmanville, Soper and Wilmot Creeks drainage basin,
S Credit River drainage basin,
S Grand River drainage basin,
S Holland and Black River drainage basins,
S Moira River drainage basin,
S Severn Sound drainage area,
S South Nation River drainage basin,
S Thames River drainage basin, and
S Upper Nottawasaga River drainage basin (Figure In-1).

The above areas include parts of most of the physiographic regions in southern Ontario as identified by Chapman and Putnam (1984). They also include parts of all the bedrock hydrogeologic units and parts of the most important overburden aquifers in southern Ontario as described by Singer et al. (1997). In addition, a variety of land uses including urban, intensive agriculture, row crops, specialty crops, pastures, woodlots, and wetlands are found within the selected areas.

Within the selected areas, groundwater is a major source of water supply for municipalities and agricultural, commercial, industrial, rural domestic, and recreation purposes, and the dependency on groundwater is increasing over time. This dependancy has resulted in severe water shortages and aquifer mining in some locations.

The natural quality of the groundwater within the selected areas is good, but it is also susceptible to contamination in certain locations.This is especially true in areas where bedrock or sand and gravel aquifers are near or at the surface. Numerous incidents of groundwater contamination by bacteria, nitrate, road salts, and volatile organics have been reported.

1.4 DESIGN METHODOLOGY

The design of the groundwater monitoring networks for the selected areas made extensive use of the MOE Water Well Information System. In addition, available technical reports and maps related to the physiography, geology, and hydrogeology of these areas provided indispensable information for the design of the networks. The reports provided background information about the hydrogeologic characteristics of the areas, while the maps served to define the areal extent of various physiographic and geologic features and as effective backgrounds to display the hydrogeologic information.

In designing the groundwater monitoring networks for the selected areas, the following factors were considered important:

- groundwater occurrence within various bedrock and overburden deposits,
- the water-yielding capabilities of the deposits,
- the susceptibility of groundwater to contamination, and
- groundwater use.

As part of the design process, the number of water wells that tap the various deposits, their designated uses (agricultural, commercial, domestic, industrial or municipal), and their water-yielding capabilities were considered important indicators that warranted special consideration.

The number of water wells and their designated uses are good indicators of the significance of groundwater as a source of water supply within an area. Further, the number of wells that tap a given bedrock or overburden formation is an indicator of the relative importance of the formation as a source of water supply. In areas where the overburden is thin or absent, as is the case in parts of the Canadian Shield, the bedrock could be the only source of water supplies. On the hand, in areas where the overburden is thick, as is the case within the Oak Ridges moraine, the overburden becomes the main source of water supplies. In many areas of Ontario both the bedrock and the overburden are important sources of water supplies.

The water-yielding capabilities of wells and the aquifers they tap are usually determined through long-term pumping tests which are intended to calculate the coefficients of permeability (hydraulic conductivity), transmissivity, and storage. Often, however, the only available data for wells are the final drawdowns associated with pumping tests of short durations. These data can be used to calculate the specific capacity values for the wells. In general, high specific capacities are indicative of high transmissivities and, consequently, high water-yielding capabilities.

In designing the monitoring networks for the selected areas, the specific capacity values for various wells served as useful indexes to describe the water-yielding characteristics of the wells and the formation(s) they tap.

1.4.1 Design Considerations Related to the Susceptibility of Groundwater to Contamination.

The susceptibility of groundwater to contamination is another major factor that has to be addressed when designing a monitoring network. Groundwater is susceptible to contamination from many types of pollutants that can travel rapidly downward from the surface to the water table. Pollutants originate either from point or non-point sources.

Potential point sources of pollution include municipal sanitary landfill sites, industrial waste storage and disposal sites, municipal and industrial liquid waste impoundments, major spills, underground gasoline storage tanks, mine tailings, radioactive wastes, coal tar sites, coal and coal ash from thermal power plants, PCB storage areas, deep well injection from industrial waste and brine disposal lagoons. Non-point sources that can impact the groundwater quality include industrial and municipal operations (pipelines, minor spills, and road de-icing salts), agricultural activities (fertilizer and pesticide use, animal manure, and irrigation), urban drainage, septic systems, unprotected domestic and abandoned wells, acid rain and atmospheric fallout.

In 1981 MOE initiated the Groundwater Susceptibility to Contamination Map Series Program. As part of this program, twenty-six maps for various areas in southern Ontario were published. When evaluating the potential susceptibility of groundwater to contamination within each of these twenty-six areas, the following factors were considered:

S permeability of near surface materials,
S direction of groundwater movement,
S presence of shallow aquifers, and
S groundwater use in the area.

As part of the above program, seven different hydrogeologic environments were identified in Ontario. These environments are: areas of carbonate bedrock that are at or close to the surface; the Canadian Shield; areas of surficial sand and gravel associated with kame deposits; areas of surficial sand with a minor amount of gravel; areas of surficial clay deposits; areas of surficial silt, clay and till; and areas of surficial sand and gravel among till.

A high, low, and variable rating system was used to determine the susceptibility of groundwater to contamination within each hydrogeologic environment. The rating system was based on the presence or absence of shallow aquifers, the permeability of surface materials, and groundwater use.

A slightly modified methodology to that used by the MOE program was used for the design of the monitoring networks in the selected areas. As described further, the modified methodology considered the presence and thickness of protective clay material.

1.4.2 Designing a Groundwater Monitoring Network in the Bedrock

As part of designing the monitoring network within the bedrock of a selected area, the following steps were taken.

S The bedrock wells were plotted on a bedrock geology map.
S The number and percentage of wells within each bedrock formation were identified.
S Formations with less than 5% of the wells were considered as currently not significant.
S The specific capacity values for the bedrock wells were calculated.
S Maps were prepared to show bedrock wells with the following ranges of specific capacities in l/min/m:

S	< 5	(minimal producing wells),
S	5-25	(below average producing wells),
S	25-50	(average producing wells), and
S	> 50	(above average producing wells).

S Areas containing bedrock wells with specific capacities of 25-50 and >50 l/min/m were delineated to identify average and above average water producing areas.
S A sufficient number of geologic-cross sections and panel diagrams were prepared (Figure In-2).
S All the available information was used to delineate areas within the bedrock that have high, variable (medium), and low susceptibility to groundwater contamination.

The following method was used to delineate the areas with various susceptibility to groundwater contamination:

S *high susceptibility* areas are those where the bedrock is at or near the surface or covered with sand and/or gravel materials with no impermeable layers,

S *variable susceptibility* areas are those where the overburden mantle over the bedrock consists of sandy till and/or very fine sand and silt with up to 3 m of clay material, and

S *low susceptibility* areas are those where the overburden mantle over the bedrock contains over 3 m of clay material.

The recommended areas for groundwater monitoring within the bedrock were delineated using the following method.

S Areas that are *highly recommended* for monitoring are those where groundwater in the bedrock is highly susceptible to contamination and where the wells have average or above average yields.

S Areas that are *recommended* for monitoring are those where groundwater in the bedrock has a variable susceptibility to contamination and where the wells have average or above average yields.

S Areas that are *optional* for monitoring are those where groundwater in the bedrock has a variable susceptibility to contamination and where the wells have below average yields.

1.4.3 Designing a Groundwater Monitoring Network in the Overburden

As part of designing a groundwater monitoring network within the overburden of a selected area, the following steps were taken.

S The overburden wells were plotted on a surficial geology map.

S The number and percentage of wells within each type of overburden deposits (glacial, glaciofluvial, glaciolacustrine or glaciomarine) were identified.

S Deposits with less than 5% of the wells were considered as currently not significant.

S The specific capacity values for the overburden wells were calculated.

S Maps were prepared to show overburden wells with the following ranges of specific capacities in l/min/m:

S < 5 (minimal producing wells),
S 5-25 (below average producing wells),
S 25-50 (average producing wells), and

    S > 50 (above average producing wells).

S Areas containing overburden wells with specific capacities of 25-50 l/min/m and >50 l/min/m were delineated to identify average and above average water producing areas.

S A sufficient number of geologic-cross sections and panel diagrams were prepared.

S All the available information was used to delineate areas within the overburden that have *high*, *variable* (*medium*), and *low* susceptibility to groundwater contamination.

The following method was used to delineate the areas with various susceptibility to groundwater contamination:

S *high susceptibility* areas are those where the overburden consists of thick sand and gravel deposits which form a surficial aquifer,

S *variable susceptibility* areas are those where the overburden consists of sandy till and/or very fine sands and silts with up to 3 m of clay material, and

S *low susceptibility* areas are those where the overburden mantle consists of clay till or over 3 m of clay material.

The recommended areas for groundwater monitoring within the overburden were delineated using the following method.

S Areas that are *highly recommended* for monitoring are those where groundwater in the overburden is highly susceptible to contamination and where wells have average or above average yields.

S Areas that are *recommended* for monitoring are those where groundwater in the overburden has a variable susceptibility to contamination and where wells have average or above average yields.

S Areas that are *optional* for monitoring are those where groundwater in the overburden has a variable susceptibility to contamination and where wells have below average yields.

1.5 POTENTIAL PARTNERS

A key component of this program is partnerships between MOE and other groups who are interested in groundwater. The program will be delivered in cooperation with these groups. This cooperative approach would ensure that the program covers a wide range of interests and utilizes current resources that are already being used for groundwater monitoring.

Potential partners who are already conducting monitoring program will be encouraged to make their data available for inclusion into the Provincial Groundwater Monitoring Information System. Those potential partners will also be encouraged to enter into individual arrangements with MOE. Such arrangements could include specific technical assistance to the partners such as the development of detailed hydrogeologic maps for local groundwater resources or training in the use of the electronic MOE water well database. In addition to individual arrangements made with the partners to serve specific local needs, MOE, as custodian of the database, will use its hydrogeologic expertise and knowledge of provincial environmental issues to provide:

S annual reports on environmental trends in groundwater conditions, with special attention to emerging potential problems related to quality or quantity, and
S advisories to specific municipalities or regions where observations indicate the need for attention.

In exchange, the partners will be asked to provide assistance regarding the implementation of the monitoring network and the collection and analyses of samples.

1.6 ACKNOWLEDGMENTS

This report was prepared under the general supervision of E. Piché, Director and J. Fleischer, Manager, Water Monitoring Section, both of the Monitoring and Reporting Branch, Ministry of the Environment.

The report would have not been possible without the substantial support and valuable participation of many persons. Appreciation is expressed to Dr. R. Thomas and Dr. D. Rudolph of the University of Waterloo, Dr. K. Howard of the University of Toronto, and T. Beukeboom, D. Conrad, J. Gehrels, and R. Hudgins of the Ministry of the Environment for their invaluable participation and suggestions.

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Singer, S.N., Cheng, C. K., and Scafe, M.G. 1997. The hydrogeology of southern Ontario; Volume 1, Hydrogeology of Ontario Series (Report 1), Ministry of the Environment, ISBN 0-7778-6006-6.

FIGURES

Figure In -1.	Selected basins for groundwater monitoring in southern Ontario.
Figure In -2.	A panel diagram showing the overburden subsurface geology in the southeastern part of the Holland and Black River drainage basins.

CHAPTER TWO

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE BIG OTTER CREEK DRAINAGE BASIN

By

S.N. Singer, A. McDonald, and C.K. Cheng

2.1 LOCATION

The Big Otter Creek drainage basin is located in southwestern Ontario between longitudes 80°29' and 80°57' W and latitudes 42°38' and 43°03' N. The creek and its tributaries drain an area of about 713 km^2 which comprises parts of the counties of Brant, Elgin, Middlesex, Norfolk, and Oxford.

The Big Otter Creek rises at an elevation of about 260 m above mean sea level (a.s.l.) near New Durham in the relatively flat and swampy northeastern corner of the basin, travels for a distance of about 77 km, and empties into Lake Erie at Port Burwell. The main tributaries to the Big Otter Creek are the Little Otter Creek, an un-named tributary at Bayham, the Stony Creek, the Branch Creek, and the Spittler Creek.

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

2.2 LAND USE

The Big Otter Creek basin is almost entirely rural and includes only a few small urban settlements such as Tillsonburg, Norwich, Port Burwell and Vienna. The basin is a major producer of tobacco which is being cultivated mainly in the Norfolk Sand Plain. To maintain soil organic content on tobacco lands, rotation crops of rye and wheat are being cultivated. On heavier soils, corn, oats, hay and pasture are being grown and dairy farming is dominant. Also, woodlots are being maintained in poorly-drained areas.

2.3 GROUNDWATER USE

Groundwater is used in the basin to meet commercial, domestic, industrial, irrigation, livestock, and municipal needs. The availability of water and the amount required for a specific purpose dictates the method of groundwater extraction. The main types of extraction in the basin are wells and dugout ponds. The later are common in sandy soils where the water table is close to the ground surface.

The number of water wells within the Big Otter Creek basin is over 2500. Of these, about 85% are constructed in the bedrock and the remaining wells are in the overburden. Approximately, 36% of all the wells are used for rural domestic purposes and livestock watering. Also, the municipal systems for Norwich, Tillsonburg, and Otterville obtain their water supplies from groundwater sources.

Tobacco is planted extensively on the sandy soils in the basin and requires irrigation. Approximately 15% of the water used for Irrigation is from groundwater sources (wells and dugout ponds).

2.4 PHYSIOGRAPHY

The main land forms within the Big Otter Creek basin are the result of sediment deposition, erosion, and modification that occurred during glacial and post-glacial times of the Quaternary Period. These forms are comprised of end moraines, a ground moraine, the Norfolk Sand Plain, kettles, spillways, and abandoned shorelines.

Chapman and Putnam (1984) identified two main physiographic regions within the Big Otter Creek basin. The southeastern half of the basin, along the lowlands adjacent to the Big Otter Creek and the Little Otter Creek, exhibits gentle topography and is part of the extensive Norfolk Sand Plain which is a major physiographic feature of this part of Ontario. The Mount Elgin Ridges, which are located in the northern and northwestern parts of the basin, are characterized by high ridges and knob-and-kettle topography and are part of the Horseshoe Moraines physiographic region. The ridges include the St. Thomas, Norwich, and Tillsonburg end moraines.

The St. Thomas Moraine forms the northwestern boundary of the basin. It extends to the southwest from Mount Elgin as a high, well-developed ridge and to the northwest as a gently rolling feature. Southeast of St. Thomas Moraine, parallel to it, and separated from it by sand and till plains, is the Norwich Moraine. This moraine extends from just north of Norwich to Delmer as a relatively subdued and gently rolling ridge. The Tillsonburg Moraine, which is a well-developed ridge that marks the northeastern boundary of the basin, curves west and crosses the basin just north of Tillsonburg and then curves south and forms part of the western boundary of the basin.

A small ridge, which has in some places a topography characteristic of an end moraine, is located in the lower part of the basin and forms the divide between the Big Otter Creek and its tributary, the Little Otter Creek. The ridge has been mapped by Sibul (1969) as an extension of the Paris Moraine.

2.5 BEDROCK TOPOGRAPHY AND GEOLOGY

There are no bedrock outcrops in the Big Otter Creek basin, as the rock surface is now completely covered by glacial drift. The bedrock elevation ranges from about 250 m (a.s.l.) in the northern part of the basin to about 110 m (a.s.l.) near Port Burwell and appears to have a number of bedrock valleys (Figure Bi-1). The most prominent of these valleys is the one that occurs along the lower part of the Big Otter Creek and extends under most of the Little Otter Creek Valley. The general slope of the bedrock surface is toward the south at an average of 3 meters per kilometer.

Sanford (1958) identified four Palaeozoic formations within the Big Otter Creek basin, the Bass Island Formation of Silurian age, and the Delaware, Detroit River Group, and Bois Blanc Formations of Devonian age. Thurston et al. (1992), however, mapped the Delaware Formation as part of the Detroit River Group.

Figure Bi-2 shows the bedrock geology of the basin. The Bass Island Formation subcrops at the extreme northeastern corner of the basin and consists of grey to brown, fine granular dolomite. The Devonian Bois Blanc Formation subcrops as a band that crosses the northern part of the basin and consists of grey limestone and sandy limestone and dolomite with abundant nodular chert. Most of the basin is underlain by rocks of the Detroit River Group which consist of brown and buff limestone and dolomite that grade upward to finely crystalline limestone, with interbedded black shale.

2.6 OVERBURDEN THICKNESS AND GEOLOGY

The thickness of the overburden varies from about 15 m at the northern end of the basin to about 90 m at its southern end. The thinnest overburden deposits (15-30 m) extend along the valley of the Big Otter Creek from Tillsonburg in the center of the basin to Hatchley at its northeastern end. The thickest deposits (more than 75 m), on the other hand, are found in the lower parts of the basin and along its western boundaries (Figure Bi-3).

The overburden consists of glacial, glaciofluvial, and shallow-water lacustrine and fluvial deposits of Pleistocene age as well as alluvium, beach, muck and swamp deposits of Recent age. Figure Bi-4 shows the overburden geology of the basin and the locations of overburden wells. Figure Bi-4 indicates that the glacial till deposits predominate in the northwestern parts of the basin where a number of morainic ridges occur. The shallow-water lacustrine and fluvial deposits, on the other hand, cover most of the low, flat areas in the southeastern parts of the basin.

According to Sibul (1969), the oldest till exposed in the Big Otter Creek basin is a compact, stony, sand till that contains many large boulders. This till is believed to be of the same age as the Catfish Creek Till. The silty clay to clayey silt till deposits that form the St. Thomas and Norwich moraines are believed to be lower Port Stanley Till. The silt to clay till with moderate amounts of stone and pebbles, which forms the Tillsonburg Moraine, is believed to be upper Port Stanley Till.

Also, the till cap over the extension of the Paris Moraine within the Big Otter Creek basin may have been formed during a pause in the retreat of the Port Stanley ice front or during a subsequent re-advance that deposited Wentworth Till. Finally, a rolling plain, underlain by silt till, lies between the northeastern extent of the St. Thomas and Norwich moraines. The surface of the plain has been reworked by lake waters and consequently the material is difficult to identify as till.

Most of the kame and outwash deposits of glaciofluvial origin within the Big Otter Creek basin are located along the St. Thomas Moraine near Holbrook, Burgessville, and Newark. Some outwash deposits also occur near the Tillsonburg Moraine.

Shallow-water lacustrine and fluvial deposits cover the Norfolk Sand Plain. The deposits consist of fine- to-medium -grained, cross-bedded sand up to 25 m thick. Closely associated with these deposits are the remnants of abandoned shorelines which stand at elevations of 236 to 253 m (a.s.l.) and consist of beach sand and gravel, and sand dunes. These shorelines mark the locations of ancient glacial lakes Arkona, Whittlesey, and Warren.

Alluvial deposits are found along most of the Big Otter Creek. Also, bogs and swamps deposits are found in kettles, abandoned stream channels, and low depressions.

2.7 GROUNDWATER OCCURRENCE IN THE BEDROCK

According to Sibul (1969), water may be obtained anywhere in the basin from wells constructed in the bedrock but only in the northern half of the basin groundwater quality is generally fresh. Even there, the fresh water is restricted to the upper zone of the bedrock and deep wells will encounter mineralized water which is not of economic value at present. Therefore, the poor natural water quality of groundwater within the bedrock rather than the availability of water is the critical factor.

Sibul (1969) notes that the configuration of groundwater levels within the bedrock appears to be a subdued reflection of the surface topography. By and large, groundwater divides and local divides coincide closely with topographic divides. Groundwater flows towards the Big Otter Creek from elevations ranging from 280 to 300 m (a.s.l.) in the northwestern corner of the basin to elevations between 160 to 200 m (a.s.l.) in the lower end of the basin.

Figure Bi-2 shows the locations of all the bedrock wells within the Big Otter Creek basin. The figure indicates that there are no wells constructed within the Bass Island Formation and only 17 wells have been constructed within the Bois Blank Formation. All the remaining bedrock wells have been constructed within the Detroit River Group hydrogeologic unit.

Singer et al. (1997) estimated the geometric mean of the transmissivity distribution for the Bass Island Formation to be about 30 m^2/day based on a sample of 739 water wells in southwestern Ontario. Further, the authors estimated the geometric mean of the tranmissivity distribution for the Bois Blank Formation to be about 40 m^2/day based on a sample size of 1,069 wells, and the geometric mean of transmissivity distribution for the Detroit River Group to be about 31 m^2/day based on a sample size of 6,762 wells. The authors describe the water-yielding capabilities of the three hydrogeologic units as being very good to excellent.

Short-term pumping tests are available for 232 bedrock wells within the basin. Of these, 54 wells (23.3 %) have specific capacities less than 5 l/min/m (Figure Bi-5), 98 wells (42.2 %) have specific capacities between 5 and 25 l/min/l (Figure Bi-6), 20 wells (8.6 %) have specific capacities between 25 and 50 l/min/m (Figure Bi-7), and 60 wells (25.9 %) have specific capacities higher than 50 l/min/m (Figure Bi-8). Based on the spatial distribution of high capacity bedrock wells on Figure Bi-8, it is possible to conclude that the majority of these wells are located within the Detroit River Group.

2.8 GROUNDWATER OCCURRENCE IN THE OVERBURDEN

Compared to the bedrock, the overburden is a significant source of groundwater within the Big Otter Creek basin. The main overburden aquifers are the coarse, sorted sand and gravel deposits that are either exposed at the ground surface or exist at various depths within the overburden.

Figure Bi-5 shows the locations of the overburden wells within the Big Otter Creek basin. The figure indicates that the wells, with the exception of the lower end of the basin, are equally distributed throughout the basin. Figure Bi-6, however, indicates that most of the low capacity wells with specific capacities of less than 5 l/min/m are associated with the till deposits that extend over the northwestern half of the basin. On the other hand, the majority of the highly productive wells with specific capacities of over 50 l/min/m are associated with the Norfolk Sand Plain. The plain is permeable and thick enough in most places to provide adequate domestic supplies to water wells. Many springs have formed at the contact between the Norfolk Sand Plain and the underlying clay along the Little Otter Creek Valley. The springs have been developed for the Vienna water supply and for many domestic supplies.

The high capacity wells that are located within the morainic ridges and the intervening till plains obtain their water supplies from sand and gravel aquifers that occur at various depths within the overburden. The proportion of sand and gravel strata within the overburden decreases markedly toward the lower end of the basin.

Data related to short-term pumping tests are available for 1,240 wells in the basin. The data indicate that 336 wells (27.1%) have specific capacities ranging from 1 to 5 l/min/m (Figure Bi-9); 502 wells (40.5%) have specific capacities between 5 and 25 l/min/m (Figure Bi-10);125 wells (10.1%) have specific capacities between 25 and 50 l/min/m (Figure Bi-11), and the remaining 277 wells (22.3%) have specific capacities larger than 50 l/min/m (Figure Bi-12).

Figure Bi-12 indicates that the majority of the high-capacity wells within the basin are located in Norfolk Sand Plain. A number of high capacity wells are also found in areas where till deposits outcrop at the surface.

2.9 SUGGESTED BEDROCK MONITORING AREAS

Figure Bi-13 shows the locations of bedrock wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for monitoring of groundwater in the bedrock. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials above the bedrock (Figure Bi-14).

Areas where groundwater in the bedrock is highly susceptible to contamination are defined as those where the bedrock is either near or at the surface or is covered by highly permeable sand and/or gravel deposits. Areas where the bedrock is moderately susceptible to contamination are defined as those where the overburden above the bedrock contains clay or clay till deposits that are less than 3 m in thickness. Areas where the bedrock has low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, three areas (A, B, and C) are proposed for groundwater monitoring within the bedrock. Area (A) is located in the lower part of the basin extending from the western topographic boundaries to the vicinity of Bayham, area (B) extends from the northern topographic divide to Eden, and area (C) extends as a narrow band in the northeastern part of the basin.

Areas (A) and (B) are underlain by rocks of the Detroit River Group while area (C) is underlain by the rocks of the Bois Blanc Formation. Groundwater susceptibility to contamination is high within area (C) and variable within areas (A) and (B).

2.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Bi-15 shows the location of overburden wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for groundwater monitoring. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials (Figure Bi-16).

Areas where the shallow overburden aquifers are highly susceptible to contamination are defined as those where sand and/or gravel deposits are either near or at the surface. Areas where shallow overburden aquifers are moderately susceptible to contamination are defined as those where the sand and/or gravel deposits are covered by clay or clay till deposits that are less than 3 m in thickness. Areas where the overburden aquifers have low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, three areas (D, E, and F) are proposed for groundwater monitoring in the overburden. The susceptibility of groundwater to contamination within area (D) is high, and within areas (E) and (F) it is low. Area (D) occupies the eastern half of the basin within the Norfolk Sand Plain. Area (E) is underlain mostly by clayey silt to silty clay till and extends from Delmer at the western boundary of the basin to Newark in the north east. Area (F) is located in the north western corner of the basin and is also underlain by clayey silt to silty clay till.

2.11 HISTORICAL MONITORING WELLS

According to Sibul (1969), a number of monitoring wells were used during the study of the groundwater resources of the Big Otter Creek drainage basin. Some of these wells were equipped with automatic recorders and others were measured manually. The types and locations of these wells are as follows:

Well No.1	Well is located in Port Burwell, manual measurements.
Well No.2	Well is located east of Kinglake Station, manual measurements.
Well No.3	Well is located midway on road from Straffordville to Bayham, manual measurements.
Well No.4	Well is located at Corinth, manual measurements.
Well No.5	Well is located north west of Eden, it ends in sand, automatic

	recorder. The well is part of the historical monitoring network and known as well No. 187.
Well No.6	Well is located west of Courtland, manual measurements.
Well No.7	Well is located at Delmer, it ends in silt, automatic recorder.
Well No.8	Well is located on Highway 19, west of Tillsonburg Airfield, manual measurements.
Well No.9	Well is located southwest of Otterville, manual measurements.
Well No.10	Well is located southeast of Norwich, manual measurements.
Well No.11	Well is located midway on road from Newark to Norwich, manual measurements.
Well No.12	Well is located at Holbrook, it ends in till, automatic recorder.
Well No.13	Well is located alongside railroad between Tillsonburg and Sprinford, it ends in bedrock, automatic recorder. The well is part of the historical monitoring network and has two piezometers: one in overburden (piezometer No. 176) and the other in bedrock (piezometer No.177).
Well No.14	Well is located on road between Ranelagh and Hatchley, it ends in bedrock, automatic recorder. The well is part of the historical monitoring network. It has three piezometers, two in the overburden at 9 m and 18 m depths and one in the bedrock at 24 m depth. The piezometers were assigned numbers 173, 174 and 175, respectively.

In addition, three historical monitoring wells were used in the past to monitor groundwater in the basin. The types and locations of these wells are as follows:

Well No. 175	An overburden well, 24.38 m deep, and contains two piezometers; one (Piezometer 173) is at depth of 9.75 m and the other (Piezometer 174) is at depth of 16.76 m. The well is located in Brant County, Burford Township, Concession 13, Lot 19.
Well No. 177	A bedrock well, 37.49 m deep, and contains a piezometer (Piezometer No. 176) within the overburden at depth of 9.75 m. The well is located in Oxford County, South Norwich Township, Concession 9, Lot 27.
Well No. 187	An overburden well, 5.18 m deep, and located in Elgin County, Bayham Township, Concession 10, Lot 22.

Figure Bi-17 shows the locations of the historical monitoring wells and Appendix I gives the geographic coordinates of these wells.

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FIGURES

Key Map - Bi	A transparency to be used with other figures for orientation purposes.
Figure Bi - 1	Bedrock topography in the Big Otter Creek drainage basin.
Figure Bi - 2	Bedrock geology in the Big Otter Creek drainage basin.
Figure Bi - 3	Overburden thickness in the Big Otter Creek drainage basin.
Figure Bi - 4	Overburden geology in the Big Otter Creek drainage basin.
Figure Bi - 5	Bedrock wells with specific capacities equal to or less than 5 l/min/m.
Figure Bi - 6	Bedrock wells with specific capacities between 5 and 25 l/min/m.
Figure Bi - 7	Bedrock wells with specific capacities between 25 and 50 l/min/m.
Figure Bi - 8	Bedrock wells with specific capacities higher than 50 l/min/m.
Figure Bi - 9	Overburden wells with specific capacities equal to or less than 5 l/min/m.

Figure Bi -10 Overburden wells with specific capacities between 5 and 25 l/min/m.

Figure Bi -11 Overburden wells with specific capacities between 25 and 50 l/min/m.

Figure Bi -12 Overburden wells with specific capacities higher than 50 l/min/m.

Figure Bi -13 Suggested areas for monitoring groundwater in the bedrock.

Figure Bi -14 Panel diagram showing the geologic logs of bedrock wells with specific capacities higher than 25 l/min/m.

Figure Bi -15 Suggested areas for monitoring groundwater in the overburden.

Figure Bi -16 Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 50 l/min/m.

Figure Bi - 17 Locations of historical monitoring wells in the Big Otter Creek drainage basin.

CHAPTER THREE

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE BOWMANVILLE, SOPER AND WILMOT CREEKS DRAINAGE BASIN

By

S.N. Singer, C.K. Cheng, and I. Solovykh

3.1 LOCATION

The Bowmanville, Soper and Wilmot Creeks drainage basin is located in southern Ontario on the north side of Lake Ontario between longitudes 78° 35' and 78° 51' W and latitudes 43° 53' and 44° 04' N in the Regional Municipality of Durham.

The basin has an area of about 270 km^2, a length of about 18 km in a northwest-southeast direction, and a width which varies between 6 and 14 km in an east-west direction. Land surface elevations vary from 74 m (a.s.l.) at Lake Ontario to about 375 m (a.s.l.) in the extreme northeastern part of the basin. The three main drainage systems in the basin are the Bowmanville, Soper and Wilmot Creeks, all of which flow southeasterly towards Lake Ontario. In addition, there are four small unnamed creeks with drainage areas ranging from about 1 to 4 km^2 which empty directly into Lake Ontario.

The Bowmanville Creek rises in the Oak Ridges Moraine at an elevation of about 305 m (a.s.l.) and flows southeast for a distance of about 22 km to its outlet into Lake Ontario at Port Darlington. The creek drains an area of 86.5 km^2 and has a total fall of about 228 m with an average gradient of about 9 meters per kilometer.

The Soper Creek rises in the Oak Ridges Moraine at an elevation of about 290 m (a.s.l.). It flows south to its confluence with the Bowmanville Creek about 0.8 km north of Port Darlington at an elevation of about 75 m. The creek drains an area of about 78 km^2. It has a length of about 20.2 km, a total fall of about 204 m, and an average gradient of about 10 meters per kilometer.

The Wilmot Creek rises in the Oak Ridges Moraine at an elevation of about 331 m (a.s.l.) and flows south to its outlet into Lake Ontario. The creek drains an area of about 88.8 km^2. It has a length of about 21.2 km, a total fall of about 225 m, and an average gradient of about 12 meters per kilometer (Singer 1981).

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

3.2 LAND USE

Most of the Bowmanville, Soper and Wilmot Creeks basin is in agriculture. The basin also contains quarries, woodlands, and recreational areas. The main urban centers within the basin are Bowmanville, Newcastle, and Orono. Other smaller urban areas include Hampton, Enniskillen, Haydon, and Leskard.

3.3 GROUNDWATER USE

Groundwater is a major source of water supply within the basin and it is used for rural domestic supply, livestock watering, municipal supply, and irrigation purposes. The total number of water wells within the basin on file with the Ministry of the Environment is 1,696. Of these, 180 are bedrock wells (10.6%), 1,437 are overburden wells (85%), and the remaining wells are of unknown type.

Three communities within the basin have municipal water-supply systems. These communities are Bowmanville, Newcastle and Orono. The Tyrone springs are used as a water supply source for the Town of Bowmanville. These springs satisfy approximately half of the water requirements of the town with the other half being obtained from Lake Ontario. Newcastle and Orono, on the other hand, utilize groundwater supplies exclusively.

3.4 PHYSIOGRAPHY

The physiography of the Bowmanville, Soper and Wilmot Creeks basin is a direct result of the deposition and erosion processes during glacial and post-glacial times. The three major physiographic units in the basin, the Lake Iroquois Plain, the Till Plain, and the Oak Ridges Moraine, were described by Gravenor (1957) and Chapman and Putnam.

After the retreat of the last glacier, the present lake Ontario basin was occupied by a glacial lake, Lake Iroquois which reached higher levels than Lake Ontario. The abandoned Lake Iroquois shoreline lies from 6 to 10 km north of the present-day shoreline of Lake Ontario and tilts upwards to the east within the area. Sand and gravel bars and beach terraces are well displayed at the surface along the abandoned shoreline.

Large deltas were formed at the mouths of the Bowmanville, Soper and Wilmot Creeks as they emptied their waters into Lake Iroquois or a lower level post-glacial lake, creating a belt up to 3 km in width to the south of the abandoned shoreline. For the most part, this belt is composed of fine gravel and sand. Farther south, the offshore deposits of Lake Iroquois consist mainly of silt and clay. In the eastern, central and northwestern parts of the Iroquois Plain, till is exposed locally at the surface. In addition, two small drumlins which are located to the northeast of the Town of Bowmanville interrupt the plain.

The Till Plain is the second major physiographic region within the basin and extends over most of its central parts. Chapman and Putnam (1984) considered this plain as a part of the South Slope physiographic region which extends from the Niagara Escarpment to the Trent River and covers about 2,433 km^2. In doing so, Chapman and Putnam related this plain to the Lake Ontario Lobe. The topography of the Till Plain varies from regularly gentle to fairly steep slopes, yet presents a noticeable contrast to the irregular features of the Oak Ridges Moraine to the north and the flatter rolling surface of the Iroquois Plain to the south.

The Oak Ridges Moraine forms the northern part of the basin and is considered as one of the most significant physiographic regions in southern Ontario, extending from the Niagara Escarpment to the Trent River. The topography of the moraine is characterized by hilly, irregular surfaces, and it is marked by knolls, hummocks and closed depressions. Its elevation ranges between 275 and 375 m (a.s.l.) with the highest points being at the extreme northeastern parts of the basin (Singer 1981).

3.5 BEDROCK TOPOGRAPHY AND GEOLOGY

The bedrock in the Bowmanville, Soper and Wilmot Creeks basin is completely obscured by the overburden and its elevation ranges from approximately 60 to 71 m (a.s.l.) along the Lake Ontario shoreline to over 150 m (a.s.l.) in the Oak Ridges Moraine (Figure Bo-1). Based on the MOE water well records, it appears that the Oak Ridges Moraine is underlain by a bedrock ridge which may have acted as a pre-glacial drainage divide, although the lack of data precludes any detailed interpretation. Three bedrock valleys can be seen in the lower parts of the basin and appear to coincide roughly with the existing valleys of the Bowmanville, Soper and Wilmot Creeks.

A very small area in the southeastern corner of the basin is underlain by the Lindsay Formation of the Simcoe Group which is of Upper Ordovician age. A large part of the basin, however, is underlain by the younger Blue Mountain Formation (formerly the Whitby Formation) of Middle Ordovician age (Thurston et al.1992).

The Lindsay Formation is a grey to greenish-gray, fine- to coarse-grained limestone. The formation contains argillaceous beds, shale partings and abundant nodules. The contact with the younger Blue Mountain Formation is reported to be an unconformity. The Blue Mountain Formation consists of highly calcareous brownish or black shales with some limestone beds (Figure Bo-2).

3.6 OVERBURDEN THICKNESS AND GEOLOGY

In general, the overburden within the Bowmanville, Soper and Wilmot Creek basin thickens from less than 6 m along the Lake Ontario shoreline to about 215 m along the Oak Ridges Moraine in the north (Figure Bo-3). The overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age with minor amounts of alluvial, beach, muck and swamp deposits of Recent age (Figure Bo-4).

The glacial deposits within the basin are mainly in the form of ground moraine and associated drumlins (Singer 1974; Funk 1977). The ground moraine is composed of sandy till and can be found mainly between the abandoned Lake Iroquois shoreline in the south and the base of the Oak Ridges Moraine to the north. Within these limits, the ground moraine constitutes a part of the South Slope physiographic region. A second and smaller area of a ground moraine extends to the south of the abandoned Lake Iroquois shoreline and constitutes a part of the Lake Iroquois Plain physiographic region.

A few well-formed, oval-shaped drumlins, composed of sandy till with abundant stones, are scattered within the basin. Both the ground moraine and the drumlins are believed to have been laid down by the Lake Ontario Lobe.

The glaciofluvial deposits within the basin consist of the Oak Ridges Moraine, a few kames, and outwash plains. According to Gravenor (1957), the Oak Ridges Moraine was formed between two ice lobes, one is the Lake Ontario Lobe advancing from the southeast, and the other is the Northern Lobe, a predecessor to the Simcoe Lobe, advancing from the northeast. The area between the two lobes was filled with great volumes of sand and gravel up to 150 m in thickness. Gravenor (1957) reported a surprising lack of incorporated till in the moraine and concluded that the melting of the ice between the two ice lobes was rapid and the floods of water pouring out left much stratified material, but little till.

A small area to the southwest of the Village of Enniskillen was identified by Gravenor (1957) as kame. The kame area is composed of sand, gravel and minor amounts of till deposits and it was built, probably, in contact with the ice. Also, an area of outwash sediments of sand and gravel is found south of the Oak Ridges Moraine and immediately north of the abandoned Lake Iroquois shoreline, extending between the Wilmot Creek in the east and the Bowmanville Creek to the west. According to Gravenor (1957), these sediments represent materials deposited by streams that flowed into Lake Iroquois.

Glaciolacustrine sediments were deposited in Lake Iroquois along and to the south of the abandoned shoreline where sand and gravel bars and beach terraces are common. The thickness of these deposits range from 1 to 8 m. A sandy belt, up to 3 km in width, occurs south of the abandoned shoreline. In places, the thickness of the sand reaches 30 m. Further south, the offshore deposits of Lake Iroquois consist mainly of silt and clay up to 8 m in thickness.

In the eastern, central and northwestern parts of the Iroquois plain, till is exposed at the surface. The exposed till has a surface elevation equal to or lower than the silt and clay deposits of Lake Iroquois indicating that it was flooded by water. Gravenor (1957) believes that these low lying till surfaced areas represent locations where strong currents prevented the deposition of silt and clay.

Along most of the main stream valleys there are several terraces formed when the streams were flowing at higher levels. The terrace deposits are composed of mixtures of gravel, sand, silt and clay. Also, along most of the Lake Ontario shoreline there is a beach of gravel and sand between the base of the bluffs and the lake. In several localities, sand bars have been built across bays. The most important bays enclosed by these barriers are the harbor of Port Darlington on the Bowmanville Creek and the harbor of Newcastle on the Wilmot Creek.

The stratigraphic succession as exposed in the Lake Ontario bluffs within the Bowmanville, Soper Creeks basin was described by Singer (1974) who identified five units: Proglacial Lake Unit consisting mainly of clay, Upper Glacial Unit consisting of two till sheets separated by sand and silt, Middle Glacial Unit consisting of till, the Clarke Deposits Unit consisting of clay and sand, and a Lower Glacial Unit consisting of till.

The stratigraphic succession as revealed in wells drilled in the Oak Ridges area indicates the presence of at least five major units: an Upper Unit consisting of glacial and glaciofluvial deposits, a Middle Unit consisting of glaciolacustrine and glaciofluvial deposits, a Lower Unit consisting of glaciofluvial deposits, and a Basal Unit consisting of glacial deposits (Singer 1981).

3.7 GROUNDWATER OCCURRENCE IN THE BEDROCK

Groundwater occurs in fissures, joints and bedding planes of the bedrock formations. The development of the fracture system within the bedrock is relatively limited. Further, the widening of these fractures and the formation of solution cavities due to dissolution of the calcium carbonate in the limestone by chemically aggressive water appears to be of minor importance in the basin.

Over 180 wells are completed in the bedrock. Most of these wells are located within the Iroquois Plain physiographic unit where the thickness of the overburden is small. It would appear that groundwater supplies obtained from the bedrock come mainly from its upper part because most of the bedrock wells penetrate only the upper few meters of the bedrock. Four wells are reported to penetrate the bedrock from 21 to 24 m, one well to 72 m and another to 91 m. These deep wells are either dry or have a very low yield.

In general, the majority of wells completed in the bedrock are suitable for supplying domestic requirements only. The production from these wells ranges from a few liters per day to a few liters per minute, with some of the wells being pumped dry under normal usage. Short-term pumping tests are available for 70 wells. Of these, 56 wells have specific capacities of less than 5 l/min/m (Figure Bo-5), eight wells have specific capacities between 5 and 25 l/min/m (Figure Bo-6), three well with specific capacities between 25 and 50 l/min/m (Figure Bo-7), and three wells with specific capacities higher than 50 l/min/l (Figure Bo-8).

The specific capacity data for the bedrock wells indicate that the bedrock in the Bowmanville, Soper and Wilmot Creeks basin has a low water-yielding capacity and is of limited importance as an aquifer. The overburden overlying the bedrock in the basin contains a number of units which are characterized by very low permeability. Four of these units, namely, the Basal Till, the Lower Till, the lower member of the Clarke Deposits Unit and the Middle Till are found at the bottom of the overburden section overlying the bedrock. As a result of this geological setting, Singer (1981) concluded that the net groundwater recharge to the bedrock in the basin is small. Also, the regional groundwater flow within the bedrock takes place mainly within its top few meters and the bulk of the groundwater recharge, transmission and discharge occur within the overburden.

3.8 GROUND WATER OCCURRENCE IN THE OVERBURDEN

In general, the groundwater availability in the overburden ranges from poor to good. Most wells are used for domestic supplies and livestock requirements. Locally, the overburden aquifers are the most productive sources of groundwater within the basin

Four tills were identified in the basin, the Basal Till, the Lower Till, the Middle Till and the Upper Till. All the tills are heterogeneous, unsorted mixtures of particles ranging in size from fine clay to boulders. Both the Lower and Middle tills, which overlie the Basal Till, are dense and contain an exceptionally high percentage of silt and clay that make them practically impermeable. This hydrogeologic characteristic of both tills hinders the leakage of water to underlying formations.

The Upper Till is the predominant surface deposit in the basin. This till, although sandy in texture, contains a high percentage of silt and clay. The result is that low permeability is an inherent characteristic of the till. Nevertheless, the till is not completely impermeable and it permits leakage of water to the sand and gravel deposits which may be present at depth. Wells constructed in the till often encounter silt and sand deposits. These deposits, which appear to be discontinuous, commonly yield adequate water supplies to meet domestic needs and livestock's requirements. If sand or gravel deposits are not encountered by the wells, their water yields are usually poor.

The sand and gravel deposits of glaciofluvial and glaciolacustrine origin constitute the most important overburden aquifers within the basin. In general, these aquifers are highly permeable and yield water more readily to wells and springs. Their importance, however, as sources for water supply, is a function of their areal extent, thickness and geologic setting.

Data collected from deep observation wells drilled in the Oak Ridges area indicate the presence of a capping of sand and gravel with minor amounts of silt and till deposits. The sand and gravel deposits are displayed at the surface throughout most of the Oak Ridges area and represent the most important overburden aquifer within the basin. The thickness of the aquifer ranges from a few meters up to100 m. It has a knob-and-kettle relief with virtual lack of surface drainage. Rain and snowmelt infiltrate readily through the sandy topsoil and either return back to the atmosphere via evapotranspiration or percolate down to recharge the groundwater whenever the soil moisture is above field capacity. This leaves little or no water for overland flow.

Because the Oak Ridges Aquifer is underlain by till deposits which have lower permeability, the bulk of groundwater moves laterally within the aquifer and issues along the base of the ridges as springs and seepage faces to become a part of the surface runoff cycle. A small portion of the water leaks through the overburden and reaches the bedrock to become part of the regional groundwater flow system. Hence, the Oak Ridges Aquifer acts as a major recharge zone, whereas its base acts as a major discharge zone.

Few wells were drilled in the Oak Ridges Aquifer within the basin. This makes an evaluation of the water yielding characteristics of the aquifer from water wells data a difficult task. A baseflow analysis of the streamflow at station W-1, which drains 10.8 km^2 of the aquifer, gives an average groundwater discharge of 10 $l/s/km^2$ (Singer 1981).

An outwash plain that extends between Hampton on the west, Enniskillen and Tyrone to the north, Orono to the east, and the abandoned Lake Iroquois shoreline to the south represents the second most important aquifer in the basin. The Outwash Aquifer, which consists of sand and gravel, ranges in thickness from 2 to 24 m. It covers an area of about 20 km^2 and it is underlain by a sandy till. Its surface is intersected by the Bowmanville, Soper and Wilmot Creeks and their tributaries. Excess water from rain and snowmelt percolates to the aquifer and moves mainly laterally to the nearest streams to discharge as baseflow.

Sand and gravel bars and beach terraces,1 to 8 m thick, are well displayed at surface along the abandoned Lake Iroquois shoreline. Immediately to the south of these deposits there is a flat, deltaic belt up to 3 km in width, composed for the most part of fine-grained gravel and sand. Logs of wells drilled within this deltaic belt and particularly those located to the southwest of Gaud Corners on the Bowmanville Creek, approximately 1.6 km south of Stephens Gulch on the Soper Creek and immediately to the south of Orono on the Wilmot Creek, indicate the presence of sand beds that have a continuous thickness of over 30 m. The Lake Iroquois sand and gravel bars and the associated deltaic belt represent the third most important surficial aquifer in the basin.

Figure Bo-3 shows a number of bedrock valleys which are indicative of preglacial drainage. Logs of wells which penetrate the valleys, which are located to the east of the Town of Bowmanville and in the vicinity of the Village of Newcastle and to its north, indicate the presence of gravel-like deposits up to 6 m in thickness. The water-yielding characteristics of these deposits range from adequate to excellent depending on their thickness and they can provide enough water supply for domestic and farm needs. In addition, the water supply for the Village of Newcastle is believed to originate from these channel deposits.

Over 1,430 wells are completed in the overburden. Specific capacity data are available for 1,046 wells. Of these, 417 wells (39.8%) have specific capacities less than 5 l/min/m (Figure Bo-9), 489 wells (46.7) have specific capacities between 5 and 25 l/min/m (Figure Bo-10), 67 wells (6.4 %) have specific capacities between 25 and 50 l/min/m (Figure Bo-11), and 73 wells (6.9%) have specific capacities more than 50 l/min/m (Figure Bo-12).

Figure Bo-12 indicates that the wells with specific capacities higher than 50 l/min/m are located within the Oak Ridges Moraine, the till plain, the outwash plain, the deltaic sand plain, and the clay plain. All these wells tap sand and/or gravel deposits at various depths.

3.9 MONITORING GROUNDWATER IN THE BEDROCK

As indicated earlier, the analysis of specific capacity data for bedrock wells indicates that the bedrock (mainly the Blue Mountain Formation) is of limited importance as an aquifer in the Bowmanville, Soper and Wilmot Creeks basin. Only 10.6% of the wells in the basin are bedrock wells and the overwhelming majority of these wells have specific capacities less than 5 l/min/m. Given these facts, a large area extending from the Oak Ridges to Lake Ontario has been identified on Figure Bo-13 for optional monitoring of groundwater within the bedrock. The susceptibility of groundwater to contamination within this optional area is low (Figure Bo-14).

3.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Bo-15 shows the location of overburden wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for groundwater monitoring. Groundwater within the suggested areas has either a high, a variable, or a low susceptibility to contamination. The susceptibility of groundwater to contamination was determined based on information related to the thickness and type of overburden materials (Figure Bo-16).

Areas where the shallow overburden aquifers are highly susceptible to contamination are defined as those where sand and/or gravel deposits are either near or at the surface. Areas where shallow overburden aquifers are moderately susceptible to contamination are defined as those where the sand and/or gravel deposits are covered by clay or clay till deposits that are less than 3 m in thickness. Areas where the overburden aquifers have low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, six areas (A, B, C, D, E, and F) are proposed for groundwater monitoring in the overburden. Groundwater has low susceptibility to contamination in area (A), a variable susceptibility to contamination in areas (C), (D), and (E), and a high susceptibility to contamination in areas (B) and (F).

Area (A) is located within the lower part of the Wilmot Creek watershed between Newcastle and the main channel of the creek. The area is covered by glaciolacustrine clays of Lake Iroquois. Area (B) is located to the east of the main channel of the Wilmot Creek between Orono and the Stalker Creek. The area is covered with glaciolacustrine sand of Lake Iroquois. Area (C) is located just to north of area (B) and is underlain by glacial till. Area (D) covers the middle parts of the Bowmanville Creek watershed and is underlain by glaciofluvial outwash deposits. Area (E) extends from Enniskillen to Tyrone and covers parts of the watersheds of the Bowmanville and Soper Creeks. The area is underlain by glacial till. Area (F) constitute the upper portions of the Bowmanville, Soper and Wilmot Creeks basin and is part of the Oak Ridges Moraine.

3.11 HISTORICAL MONITORING WELLS

Nineteen wells and piezometers ere used in the past for monitoring groundwater in the Bowmanville, Soper and Wilmot Creeks drainage basin. The locations of the wells and piezometers and their historical numbers are as follows:

Well No. 487	An overburden well that is 26.0 m deep and is located within the upper part of the Soper Creek watershed in Durham County, Newcastle Township, Concession 8, Lot 5. The well ends in fine grained sand and it is also known as well No. S - 1a.
Well No. 488	An overburden well which is located next to well No. 487. The well is 50.3 m deep, it ends in coarse grained gravel, and it is also known as well No. S -1b.
Piezometers 489, 490 and 492	The piezometers are within a bedrock well which is 48 m deep and ends in limestone. The well is located within the Soper Creek watershed in Durham County, Concession 4, Lot 6. The well is also known as well No. S - 4.

Well No. 492	An overburden well, known as well No. S -5, and is located next to well No. S - 4. The well ends in silty till and is 12.8 m deep.
Well No. 493	A bedrock well, 9.75 m deep, which is located to the northeast of Bowmanville in Durham County, Newcastle Township, Concession 2, Lot 7. The well ends in limestone and is also known as well No. S -5.
Well No. 494	An overburden well, 7.3 m deep, and ends in a sandy clay till. It is located next to well No. S - 6a and is also known as well No. S -6b.
Well No. 495	An overburden well, 16.75 m deep, and ends in fine sand. It is located in Durham County, Newcastle Township, Concession 5, Lot 35 and is also known as well No. S - 7.
Well No. W - 1	An overburden well, 45.73 m deep, and ends in a silty till. It is located within the Wilmot Creek watershed (Concession 8, Lot 31).
Well No. W - 2	A bedrock well, 154.57 m deep, and ends in limestone. It is located next to well No. W -1.
Well No. 498	A bedrock well, 65. 24 m deep, and ends in limestone. It is located northwest of Orono in Durham County, Newcastle Township, Concession 5, Lot 32.
Piezometers 499, 500, 501, and 507	The piezometers are located within two adjacent overburden wells known as well No. W - 5a (46.34 m deep) and well No. W -5b (14.33 m deep). The wells are located in Durham County, Newcastle Township, Concession 6, Lot 22.
Well No. 502	A bedrock well, 11 m deep, and ends in limestone. The well is located to the west of Newcastle in Durham County, Newcastle Township, Concession 2, Lot 32.
Piezometers 503, 504, 505 and 506	A bedrock well, 219.51 m deep, and ends in limestone. The well, which is known as well No. W - 8, is located near the northern topographic divide of the Wilmot Creek watershed in Durham County, Newcastle Township, Concession 10, Lot 28.
Well No. 508	An overburden well that ends in silty till. It is 63 m deep and is located in the northern part of the Bowmanville Creek watershed midway between Enniskillen and Burketon Station in Durham County, Newcastle Township, Concession 9, Lot 21. The well is also known as well No. B -1.
Well No. 509	An overburden that ends in silty till. It is 11.5 m deep and is located within the Bowmanville Creek watershed to the

	southwest of Enniskillen in Durham County, Newcastle Township, Concession 7, Lot 21. The well is also known as well No. B -2.
Well N0. 526	An overburden well, 131.1 m deep, and ends in clay. The well is also known as well No. W - 9 , and it is located next to well W - 8.
Piezometers 510 and 511	The two piezometers are within a well that is located in the lower parts of the Bowmanville Creek watershed in Durham County, Newcastle Township, Concession 2, Lot 12 . The well, which ends in the bedrock, is 36 m deep and is also known as well No. B - 4.

Figure Bo-17 shows the locations of the historical monitoring wells and Appendix I gives the geographic coordinates of these wells.

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FIGURES

Key Map - Bo	A transparency to be used with other figures for orientation purposes.
Figure Bo - 1	Bedrock topography in the Bowmanville, Soper and Wilmot Creeks drainage basin.
Figure Bo - 2	Bedrock geology in the Bowmanville, Soper and Wilmot Creeks drainage basin.
Figure Bo - 3	Overburden thickness in the Bowmanville, Soper and Wilmot Creeks drainage basin.
Figure Bo - 4	Overburden geology in the Bowmanville, Soper and Wilmot Creeks drainage basin.
Figure Bo - 5	Bedrock wells with specific capacities equal to or less than 5 l/min/m.
Figure Bo - 6	Bedrock wells with specific capacities between 5 and 25 l/min/m.
Figure Bo - 7	Bedrock wells with specific capacities between 25 and 50 l/min/m.
Figure Bo - 8	Bedrock wells with specific capacities higher than 50 l/min/m.
Figure Bo - 9	Overburden wells with specific capacities equal to or less than 5 l/min/m.
Figure Bo -10	Overburden wells with specific capacities between 5 and 25 l/min/m.
Figure Bo -11	Overburden wells with specific capacities between 25 and 50 l/min/m.
Figure Bo -12	Overburden wells with specific capacities higher than 50 l/min/m.
Figure Bo -13	Optional area for monitoring groundwater in the bedrock.
Figure Bo -14	Panel diagram showing the geologic logs of bedrock wells with specific capacities higher than 5 l/min/m.
Figure Bo -15	Suggested areas for monitoring groundwater in the overburden.
Figure Bo -16	Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 50 l/min/m.

Figure Bo - 17 Locations of historical monitoring wells in the Bowmanville, Soper and Wilmot Creeks drainage basin.

CHAPTER FOUR

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE CREDIT RIVER DRAINAGE BASIN

By

S.N. Singer, C.K. Cheng, and I. Solovykh

4.1 LOCATION

The Credit River drainage basin is located in southern Ontario on the north side of Lake Ontario between longitudes 79°32' W and 80°12' W, and latitudes 43° 29' N and 43°57' N. The basin has an area of about 795 km^2 that includes a number of small watercourses in the vicinity of Lake Ontario, a total length of about 90 km, and a width that varies between 9 and 23 km. Land surface elevations within the basin vary from 75 m (a.s.l.) at Lake Ontario to about 525 m (a.s.l.) in the extreme upper parts of the basin. Most of the basin is located in Peel County but small parts of Dufferin, Halton and Wellington Counties are also included.

The Credit River rises in a hilly plateau of moraines, gravel terraces, and swamps above the Niagara Escarpment at elevations between 415 to 480 m (a.s.l.), and it empties into Lake Ontario at Port Credit. The river system consists of two branches, the Credit River in the Orangeville-Alton-Cataract area and the West Credit River in the Hillsburgh-Erin-Belfountain area. The Credit River leaves the Escarpment through a deep notch at Cataract while the West Credit descends through a similar notch at Belfountain and joins the Credit River at Credit Forks. Downstream from Credit Forks, the Credit River has built a wide alluvial plain and is joined by the East Credit River at Inglewood. From Inglewood, the river flows for about 16 km to the vicinity of Glen Williams in a narrow valley between the Escarpment and the till plain. At Glen Williams, the river swings in a southeasterly direction and follows the slope of the till plain toward Lake Ontario.

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

4.2 LAND USE

Urban, non-intensive agriculture, recreation, wetlands, and quarry operations are the main land uses within the Credit River basin. The City of Mississauga occupies the lower one-third of the basin. Other urban centres include Acton, Caledon, Erin, Georgetown, Hillsburgh, Orangeville, and Port Credit. Extraction of sand and gravel from glaciofluvial deposits is centered in Mono Township immediately northwest of Orangeville and in Erin Township near Hillsburgh.

4.3 GROUNDWATER USE

The total number of water wells within the basin on file with the Ministry of the Environment is 6,012. Of these, 3,750 (62.4%) are bedrock wells, 1,652 (27.5%) are overburden wells, and the remaining wells are of unknown type. Most of the wells are used to provide rural domestic water supplies and livestock watering.

The City of Mississauga obtains its water supply from Lake Ontario. In the rest of the basin, groundwater is used to meet all the municipal water needs. The towns of Acton, Caledon, Erin, Georgetown, Hillsburgh, and Orangeville are totally dependant on groundwater supplies.

4.4 PHYSIOGRAPHY

The present land forms within the Credit River basin are almost entirely the result of the last Wisconsinan glaciation of the ice age. Most of the land features are the result of material dumped by the ice or by meltwater as the ice advanced and retreated. Thus, the present physiography of the basin closely corresponds with its Pleistocene geology.

According to Chapman and Putnam (1984), parts of eight major physiographic regions are found in the basin. These regions include the Lake Iroquois Plain, the South Slope, the Peel Plain, the Niagara Escarpment, the Oak Ridges Moraine, the Horseshoe Moraines, the Guelph Drumlin Field, and the Hillsburgh Sandhills.

The Lake Iroquois Plain extends from Lake Ontario to the abandoned Lake Iroquois which lies from 3 to 5 km north of the present-day shoreline. The plain slopes down toward Lake Ontario with an average slope of about 10 meters per kilometer. For the most part, the plain is covered with a thin sheet, less than 1 m in thickness, of sand and silty sand. Sand and gravel bars and beach terraces, 3 to 6 m high, are well displayed at the surface along the abandoned shoreline.

The South Slope physiographic region consists of a northern part that drapes the base of the Niagara Escarpment and extends south to Highway 7 and a southern part that extends from Highway 7 to the abandoned Lake Iroquois shoreline. Part of the Palgrave Moraine and the Cheltenham Moraine are included in the northern part, while the Trafalgar Moraine is included in the southern part.

The Peel Plain physiographic region is a level to undulating tracts of clay soils that cover the central portions of Halton, Peel, and York Counties. Within the Credit River basin, the plain is bounded by the South Slope physiographic region from the north and the south. The underlying geological material of the plain is till which has been modified by a thin veneer of clay and silt.

The Niagara Escarpment physiographic region represents a topographic break produced by differential erosion of harder and softer rock in Ontario. Vertical cliffs along the brow outline the dolostones of the Cataract Group and Amabel Formation while the slopes below are carved in the red shale of the Queenston Formation. The Escarpment enters the basin at a point to the southeast of Acton where the elevation is approximately 340 m (a.s.l.). From that point, the Escarpment stands out boldly until it reaches Credit Forks. From that point northward to the basin's topographic divide, the Escarpment is almost completely hidden by morainic deposits.

The extreme western end of the Oak Ridges physiographic region is located within the Credit River basin, extending from Credit Forks in a northeasterly direction towards the basin's divide. The Oak Ridges Moraine forms the Caledon and Albion Hills and is characterized by a hilly topography with a knob-and-basin relief and surface elevations ranging from 300 to 350 m (a.s.l.).

A belt of moraines, composed mainly of a till, extends from Acton in the south, flanks Caledon from the east, and continues to Orangeville in the north. The belt includes Galt, Paris and Singhampton moraines and is part of a larger physiographic region known as the Horseshoe Moraines. From Singhampton to Caledon, the moraines lie along the brow and slopes of the Niagara Escarpment.

Chapman and Putnam (1984) considered the area extending from the Paris Moraine to the east, the Singhampton Moraine to the north, and the Orangeville Moraine to the west as part of the Guelph Drumlin Field physiographic region. The field consists of low rolling, streamlined drumlins that are separated from each other by numerous interconnecting meltwater channels.

To the west of a line extending from Hillsburgh in the south to Orangeville in the north lies a prominent topographic feature known as the Orangeville Moraine. Chapman and Putnam (1984) identified the Orangeville Moraine as part of the Hillsburgh Sandhills physiographic region. The moraine forms a nearly flat topped positive feature, which has been strongly dissected by fluvial erosion.

4.5 BEDROCK TOPOGRAPHY AND GEOLOGY

The bedrock topography in the Credit River drainage basin is similar to present-day topography (Figure Cr-1). Highest bedrock elevations between 440- 460 m (a.s.l.) are found along the basin's topographic divide in the Townships of Erin, Garafraxa, and Amaranth. From these highs, the bedrock surface forms a plateau, which slopes towards the well-defined Niagara Escarpment.

Drainage patterns within the bedrock surface above the Escarpment resemble present-day drainage patterns. Local bedrock topographic divides seem to coincide with present-day divides and three bedrock valleys appear to have been well established. One valley extends from Orangeville down the current Credit River Valley to the Escarpment, the second extends along the current Shaw's Creek Valley, and the third extends from Erin to Belfountain.

Below the Escarpment, the bedrock surface slopes gently toward Lake Ontario. From Credit Fork to Cheltenham, a bedrock valley appears to be slightly to the north and east of the present-day Credit River Valley. From Cheltenham to Port Credit, however, the bedrock valley appears to follow closely the present-day Credit River Valley.

A bedrock depression appears to exist below Highway 7 and extends south to Churchville. Sand, and silty sand of a glaciolacustrine origin outcrop at the surface where the depression occurs (Singer et al.1994).

The oldest Palaeozoic rocks within the Credit River basin are those of the Georgian Bay and Queenston Formations, both of Upper Ordovician age. The Queenston Formation is covered by rocks of the Cataract Group of Lower Silurian age. Overlying the Cataract Group, are the rocks of the Fossil Hill Formation of the Clinton Group. This, in turn, is covered by the Amabel and Guelph Formations of Middle Silurian Age.

Rocks of the Georgian Bay Formation form the bedrock surface in the southern parts of the basin extending from Streetsville to Lake Ontario. The formation has a thickness of approximately 165 m and consists of shale with interbeds of siltstone, sandstone, and limestone.

Conformably overlying the Georgian Bay Formation is the Queenston Formation which underlies a large area within the basin extending from Streetsville to the base of the Niagara Escarpment. The formation is135 to 150 m thick in the Terra Cotta area, but thins somewhat northwards. It consists of thin to thick bedded, brick-red shales.

Unconformably overlying the Queenston Formation, is the Cataract Group which consists of three formations: Whirlpool, Manitoulin, and Cabot Head. The Whirlpool Formation outcrops along the base of the Niagara Escarpment. It is about 5 m thick at Cataract and consists of thin-to massive-bedded, grey sandstone. Overlying the Whirlpool sandstone is the Manitoulin Formation which occurs along the West Credit River north of Belfountain, in the Cataract-Credit Forks area, and in the Orangeville area. The formation is 5 m thick and consists of fossiliferous, thick-bedded dolomite with shale partings and lenses of white chert. The Cabot Head Formation is about 10 m thick and outcrops sparingly in the face of the Niagara Escarpment. The formation consists of thinly-bedded, grey-green shale with thin interbeds of calcareous sandstone and limestone.

The Amabel Formation forms the cap rock of the Niagara Escarpment. It is light-grey, medium to coarsely crystalline, generally massive-bedded dolomite. The formation has reef structures and is highly fossiliferous. Although the maximum thickness exposed in the Niagara Escarpment is about 8 m at Credit Forks, the total thickness of the formation is probably greater than 30 m. The formation contains solution cavities and it is highly fractured.

The Guelph Formation rests on top of the Amabel Formation in the area of East Garafraxa at the extreme western corner of the Credit River basin. It consists of light-brown, medium to massive-bedded, uniformly textured, reefy dolomite. In well cuttings, the rocks of the Guelph Formation are not distinct from those of the Amabel Formation. This indicates that the contact between the two formations is gradational. Because of their similar composition, both formations act as one hydrogeologic unit. Their combined thickness ranges from 45 to 120 m (Figure Cr-2).

4.6 OVERBURDEN THICKNESS AND GEOLOGY

Data from bedrock wells and elevations of bedrock exposure were used to construct the overburden thickness within the basin (Figure Cr-3). At the base of the Escarpment and in the lower parts of the basin, the overburden thickness is less than one meter. Most of the area below the Escarpment, however, has an overburden thickness ranging from 10 to 20 m and can reach 50 m in some places.

Above the Escarpment, the thickness of the overburden within the Orangeville, the Oak Ridges, and the lower parts of the Paris Moraines ranges from 40 to 50 m. The thickness of the overburden within the Singhampton Moraine is between 10 and 30 m and reaches 50 m in a small area. The thickness of the overburden in the areas between the moraines ranges from 20 to 30 m. At a few places, where the bedrock is close to the surface, the thickness of the overburden is limited ranging from less than one meter to a few meters.

The unconsolidated materials overlying the bedrock in the Credit River basin were deposited during the Pleistocene Period and are considered of Late Wisconsinan age. During this period, ice flowed from the northwest (Georgian Bay Lobe), the northeast (Lake Simcoe Lobe) and the east and southeast (Lake Ontario Lobe) and laid down till plains. Also, drumlins were formed under the ice and they occur as isolated hills on the till plains.

As the ice retreated, paused or slightly re-advanced, it deposited the Singhampton, Paris, and later the Galt moraines. Meltwater flowed and formed spillways (meltwater channels), parts of which are now occupied by the Credit River system. Outwash plains and terraces were also formed by the sediment laden waters flowing off the ice masses.

Five tills have been identified within the basin: Newmarket Till, Wentworth Till, Port Stanley Till, Tavistock Till and Halton Till (Cowan and Sharpe 1973; Cowan 1976). The first three tills are sandy silt tills, whereas the other two tills are silt to clay silt tills (Figure Cr-4).

Within the Credit River basin, Newmarket Till outcrops in Mono and Caledon Townships within a belt of rolling to hummocky topography consisting largely of the Singhampton Moraine. The till represents an advance of the Lake Simcoe Lobe from the northeast and the Singhampton Moraine marks the outer limit of this till within the basin.

Newmarket Till is a sandy silt till containing numerous lenses of stratified drift. Its thicknesses is between 10 and 30 m. According to Cowan (1976), the lithology of the till appears to vary considerably. Generally, however, a significant percentage of materials from Ordovician rocks and from the Cataract Group are present.

Wentworth Till was named after its type-area in Wentworth County. According to Cowan (1976), this till is the result of a glacial advance from the Lake Ontario basin. Within the Credit River basin, Wentworth Till forms a belt of hummocky topography extending from Acton in the southwest to the headwaters of the Caledon Creek in the northeast, and consists largely of the Paris and Galt moraines. A few drumlins are associated with the till and are located on the eastern flank of the Paris Moraine in the Town of Caledon. The till is a sandy to silty sand till, often containing stones or boulders (Karrow 1968).

Port Stanley Till was deposited by an advance of the Lake Ontario Lobe from the southeast (Cowan 1976). Within the basin, Port Stanley Till occupies a broad track of rolling ground known as the Guelph Drumlin Field east of the Orangeville Moraine in the Townships of Erin and Caledon. The till is a stony to bouldery, sand silt till and is texturally similar to Wentworth and Newmarket tills though it is more dolomitic and has greater total carbonate content (Cowan 1976).

Tavistock Till takes its name from the Village of Tavistock. It was previously mapped as the "Northern Till" in the Guelph area by Karrow (1968), and as Till "C" in the Conestogo area (Karrow 1971). According to Terasmae et al. (1972), Tavistock Till was laid down during a glacial advance of the Georgian Bay Lobe. Within the basin, the till flanks and overlies the western part of the Orangeville Moraine in the Townships of East Garafraxa and Amaranth. The till is usually silt or clayey silt till, however, it is often more sandy where it overlies sand on the western flank of the Orangeville moraine (Cowan 1976).

The silt to clayey silt Halton Till covers a large area within the Credit River basin and it represents the last Wisconsinan ice advance out of the Lake Ontario basin. The till is present as a thin strip along the edge and over the lower slopes of the Niagara Escarpment. It forms the Palgrave Moraine at the extreme northwestern corner of the basin and the Trafalgar Moraine in the lower end of the basin. The till also forms a gently rolling till plain extending from the lower slopes of the Niagara Escarpment to the abandoned Lake Iroquois shoreline.

Two types of glaciofluvial deposits are found in the Credit River basin, ice-contact stratified drift and meltwater channel deposits. Most of the ice-contact stratified drift is associated with the Orangeville and the Oak Ridges moraines.

The Orangeville Moraine is located in the extreme northwestern part of the basin and extends from the Township of Mono in the northeast to Hillsburgh in the Township of Erin in the southwest. The moraine was formed between the Georgian Bay Lobe at the west and northwest, the Lake Simcoe Lobe to the north east, and the Lake Ontario Lobe to the east and southeast. According to Chapman and Putnam (1984), the Orangeville Moraine is one of the first land forms to appear in southern Ontario when the Georgian Bay and Lake Ontario lobes separated. The Orangeville Moraine consists mainly of stratified sand, silt, and gravel. The bulk of the moraine exceeds 50 m in thickness.

Ice-contact stratified drift also occurs in the northeastern parts of the Credit River basin, where deep beds of fine sand extend from the Palgrave Moraine to the southeast and the Paris Moraine to northwest. These deposits constitute the extreme western tip of the Oak Ridges Moraine and their thickness ranges from 40 to 50 m.

Meltwater channel deposits of gravel and sand were laid down in old glacial meltwater channels associated with various ice lobes that invaded the basin. One channel is known as the Hillsburgh Channel (Cowan 1976) and it extends from the south of Caledon Lakes to Hillsburgh along the southern limb of the Orangeville Moraine. The martial is outwash gravel and may exceed 7 m in thickness.

A second channel was formed when the northeasterly limb of the Orangeville Moraine was breached to initiate drainage via the Credit River channel from Orangeville to Alton. Further ice retreat extended the Credit River channel to Cataract. The deposits vary from sand and silty gravel to clean uniform stratified gravel with a thickness ranging from less than 8 m to more than15 m. The deposits are contiguous with the Caledon outwash deposits at Cataract.

A third channel, the Caledon Meltwater Channel (White 1975), traverses the rim of the Escarpment from Sleswick outside the basin past Caledon and then southwest past Cataract to Erin. The channel forms a broad valley which has a flat floor and is underlain by gravel and well-sorted fine to medium sand. According to White (1976), these deposits were laid down as the Lake Ontario Lobe stood at the Paris Moraine.

A fourth channel system occurs along the Black River and the Silver Creek and extends to Georgetown. A fifth channel, known as the Caledon East Meltwater Channel (White 1976), extends from the settlement of Albion outside the watershed to Inglewood. Below Inglewood, the channel disappears possibly beneath the present East Credit River until Terra Cotta where it appears again and continues to Glen Williams. The channel floor is relatively flat and is underlain by fine to medium sand.

Glaciolacustrine deposits in the Credit River basin are associated with Lake Peel and Lake Iroquois. The Lake Peel deposits are found in the southern part of the basin just to the north of the Trafalgar Moraine. They were laid down in a brief stand of water referred to as the Lake Peel Ponding. The thickness of the deposits is less than a meter and they consist of clay, silt and fine sand on top of Halton Till. The Lake Iroquois sediments were deposited along and to the south of the abandoned shoreline. For the most part, these deposits consist of sand and silty sand less than a meter thick.

Along most of the main stream valleys, there are terraces formed when the streams were flowing at higher levels.These terraces are composed of a mixture of gravel, sand, silt and clay. Also, tracts of poorly drained land containing organic materials occur in the meltwater channels and shallow depressions. Most of the material consists of black muck, though peat occurs in many places.

4.7 GROUNDWATER OCCURRENCE IN THE BEDROCK

As indicated earlier, the majority of water wells within the Credit River basin are bedrock wells. The principal hydrogeologic units within the bedrock in the basin include the Georgian Bay Formation, the Queenston Formation, the Cataract Group, the Clinton Group, the Amabel Formation, and the Guelph Formation.

There are a few wells within the Georgian Bay Formation and it has a poor water-yielding capability with specific capacities ranging from 0.5 to 10 l/min/m. Groundwater occurs in the upper 3-5 m within formation (Singer et al.1994).

The Queenston Formation underlies most of the area of the basin below the Escarpment and has been encountered in several wells in the Orangeville area at depths ranging from 70 to 80 m. Only the top 3 to 5 meters of the formation are weathered and may provide sufficient water supplies to meet domestic requirements. The specific capacity values for wells that are completed in the Queenston Formation range from 0.5 to 20 l/min/m (Singer et al.1994).

The Cataract Group occurs in the Cataract-Credit Forks area, and along the West Credit River north of Belfountain, and in the Orangeville area. It consists, from bottom to top, of a sequence of sandstone (about 5 m), dolomite (about 5 m), and shale (about 16 m). Specific capacity values of wells completed in Manitoulin Formation of the Cataract Group range from 1.5 to 20 l/min/m. Due to its composition and peculiar areal extent under the Amabel Formation, the Cataract Group does not constitute an important aquifer in the basin (Singer et al.1994).

The Clinton Group is limited in areal extent to the west of the Escarpment. According to Singer et al.(1994), the Clinton Group, being a thin layer of dolomite, can be combined with the dolomite of the Amabel Formation and treated as a single hydrogeologic unit.

The Amabel Formation is one of the most important and productive bedrock aquifers in the Credit River basin.The network of interconnected fissures, joints, bedding planes and solution cavities within the formation provide favorable conditions for the storage and transmission of groundwater.The aquifer is generally adequate to meet domestic requirements and at certain locations can provide adequate municipal supplies. Specific capacities of wells that tap the formation range from range from 1 to 1000 l/min/m.

The Guelph Formation occurs in a small area at the extreme northwestern part of the basin. The formation consists of dolomite that rest on top of the Amabel Formation. Thus, both formations, from a hydrogeologic point of view, act as one aquifer. Within the basin, wells that tap the Guelph Formation have specific capacities that range from 2 to 300 l/min/m (Singer et al. 1994).

Short-term pumping tests are available for 2, 841 bedrock wells within the basin. Of these, 54 wells (32.9%) have specific capacities less than 5 l/min/m (Figure Cr-5), 1,159 wells (40.8%) have specific capacities between 5 and 25 l/min/l (Figure Cr- 6), 310 wells (11.0%) have specific capacities between 25 and 50 l/min/m (Figure Cr-7), and 436 wells (15.3%) have specific capacities higher than 50 l/min/m (Figure Cr-8). Based on the spatial distribution of high capacity bedrock wells on Figure Cr- 8, it is possible to conclude that the majority of the high capacity wells are located within the Amabel and Guelph Formations.

4.8 GROUNDWATER OCCURRENCE IN THE OVERBURDEN

In general, the availability of ground water in the overburden ranges from poor to good. Most wells in the overburden are used for domestic supplies and livestock watering. Locally, overburden aquifers are the most productive sources of groundwater within the basin and provide a number of municipalities with water supplies.

According to Singer et al.(1994), the Wentworth, Newmarket, and Port Stanley Tills constitute important aquifers within the basin because of their high silt and sand contents. Data are available on short-term pumping tests for 102 wells completed in these tills. The specific capacity data for these wells range from 0.3 to 200 l/min/m. The Tavistock and Halton Tills, on the other hand, have high silt and clay content and, therefore, can provide only limited water supplies to meet domestic needs. The specific capacity data for 216 wells completed in these tills range from 0.3 to 60 l/min/m.

Wells completed in the ice-contact stratified drift deposits indicate the presence of gravel, coarse to fine sand, silt, and clay. This highly variable composition results in a highly variable water-yielding capability. Nevertheless, these deposits constitute a major aquifer in the basin and can serve as an important source of water for domestic and municipal needs. The specific capacity data for 193 wells completed in these deposits range from 0.6 to 2162 l/min/m (Singer et al.1994).

Wells completed within the meltwater channel deposits indicate the presence of gravel, coarse, medium and fine sand, and some silt and clay. Because of this highly variable composition, the water-yielding capability of these deposits is also highly variable. Nevertheless, the deposits constitute one of the best aquifers in the basin and can serve as an important source for domestic and municipal water supplies. The specific capacity data for 134 wells completed in these deposits range from 0.1 to 2993 l/min/m (Singer et al.1994).

The deltaic deposits of Lake Peel constitute the most important glaciolacustrine deposits in the basin. Due to their limited areal extent, however, these deposits constitute a minor aquifer in the lower portion of the basin. The specific capacity data for 73 wells completed in these deposits range from 0.6 to 100 l/min/m (Singer et al.1994).

Data related to short-term pumping tests are available for 890 wells that were constructed within the overburden in the basin. The data indicate that 274 wells (30.8%) have specific capacities ranging from 1 to 5 l/min/m (Figure Cr-9), 348 wells (39.1%) have specific capacities between 5 and 25 l/min/m (Figure Cr-10), 90 wells (10.1%) have specific capacities between 25 and 50 l/min/m (Figure Cr-11), and the remaining 178 wells (20.0%) have specific capacities larger than 50 l/min/m (Figure Cr-12).

4.9 SUGGESTED BEDROCK MONITORING AREAS

Figure Cr-13 shows the locations of bedrock wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for monitoring of groundwater in the bedrock. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials above the bedrock (Figure Cr-14).

Areas where groundwater in the bedrock is highly susceptible to contamination are defined as those where the bedrock is either near or at the surface or is covered by highly permeable sand and/or gravel deposits. Areas where the bedrock is moderately susceptible to contamination are defined as those where the overburden above the bedrock contains clay or clay till deposits that are less than 3 m in thickness. Areas where the bedrock has low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, three areas (A, B, and C) are proposed for groundwater monitoring within the bedrock. Groundwater susceptibility to contamination within the three areas is generally variable, however, two parts of area (B)have low susceptibility to contamination, and a third part has high susceptibility to contamination.

Area (A) is located below the Niagara Escarpment and is underlain by the rocks of the Queenston Formation. Areas (B) and (C) are located above the Escarpment and are underlain by the dolomites of the Amabel and Guelph Formations, respectively.

4.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Cr-15 shows the location of overburden wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for groundwater monitoring. Groundwater within the suggested areas has a high, variable, or low susceptibility to contamination. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials (Figure Cr-16).

Areas where the shallow overburden aquifers are highly susceptible to contamination are defined as those where sand and/or gravel deposits are either near or at the surface. Areas where shallow overburden aquifers are moderately susceptible to contamination are defined as those where the sand and/or gravel deposits are covered by clay or clay till deposits that are less than 3 m in thickness. Areas where the overburden aquifers have low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness.The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, four areas (D, E, F, G, and H) are proposed for groundwater monitoring within the overburden. The susceptibility of groundwater to contamination within areas (D) and (H) is mainly high, while it is mainly low within areas (E), (F), and (G).

Area (D) is located within the lower portion of the basin between Huttonville and Meadowvale and is underlain by glaciolacustrine sands. Area (E) extends from the Niagara Escarpment to the upper parts of the City of Mississauga and is underlain by clayey silt till. Areas (F), (G), and (H) are located above the Escarpment. Areas (F) and (G) are underlain by sand silt till, whereas area (H) is underlain mainly by glaciofluvial sand and gravel.

4.11 HISTORICAL MONITORING WELLS

Four bedrock wells and four overburden wells were used in the past for monitoring groundwater in the basin. The types and locations of these wells are as follows:

S	Well No. 65	A bedrock well, 10 m deep, located in Concession 3, Lot 13 in the lower part of the basin.
S	Well No. 167	An overburden well, 6.1 m deep, and located west of Huttonville within Concession 5, Lot 5.
S	Well No. 377	An overburden well, 33.2 m deep, and located at Georgetown.
S	Well No. 456	A bedrock well, 39.6 m deep, located in the lower part of the basin in close proximity to the topographic divide within Concession 10, Lot 1. The well contains piezometers 457, 458, 459, and 460.
S	Well No. 461	A bedrock well, 32 m deep, contains piezometers 462 and 463 and is located next to well No. 456.
S	Well No. 551	A bedrock well, 22 m deep, and located at Erin.
S	Well No. 558	An overburden well located within Caledon Township, Concession 1, Lot 6.
S	Well No. 559	An overburden well, 36.5 m deep, and located west of Acton within Concession 6, Lot 27.

Figure Cr-17 shows the locations of the historical monitoring wells and Appendix I gives the geographic coordinates of these wells.

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FIGURES

Key Map - Cr	A transparency to be used with other figures for orientation purposes.
Figure Cr -1	Bedrock topography in the Credit River drainage basin.
Figure Cr - 2	Bedrock geology in the the Credit River drainage basin.
Figure Cr - 3	Overburden thickness in the Credit River drainage basin.
Figure Cr - 4	Overburden geology in Credit River drainage basin.
Figure Cr - 5	Bedrock wells with specific capacities equal to or less than 5 l/min/m.
Figure Cr - 6	Bedrock wells with specific capacities between 5 and 25 l/min/m.
Figure Cr - 7	Bedrock wells with specific capacities between 25 and 50 l/min/m.
Figure Cr - 8	Bedrock wells with specific capacities higher than 50 l/min/m.

Figure Cr - 9	Overburden wells with specific capacities equal to or less than 5 l/min/m.
Figure Cr -10	Overburden wells with specific capacities between 5 and 25 l/min/m.
Figure Cr -11	Overburden wells with specific capacities between 25 and 50 l/min/m.
Figure Cr -12	Overburden wells with specific capacities higher than 50 l/min/m.
Figure Cr -13	Suggested areas for monitoring groundwater in the bedrock.
Figure Cr -14	Panel diagram showing the geologic logs of bedrock wells with specific capacities higher than 50 l/min/m.
Figure Cr -15	Suggested areas for monitoring groundwater in the overburden.
Figure Cr -16	Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 50 l/min/m.
Figure Cr -17	Locations of historical monitoring wells in the Credit River drainage basin.

CHAPTER FIVE

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE GRAND RIVER BASIN

By

S.N. Singer, C.K. Cheng, and I. Solovykh

5.1 LOCATION

The Grand River drainage basin is located in west central Ontario between latitudes 42^0 50' and $44^0$13' N and longitudes 79^0 29' and 80^0 57' W. The basin has an area of about 6,770 km^2, a length of about190 km, and an average width of about 35 km. Elevations within the basin vary from a high of about 535 m (a.s.l.) near Dundalk to a low of about 174 m (a.s.l.) at Lake Erie.

The Grand River rises northeast of Dundalk at about 526 m (a.s.l.) and drains into Lake Erie at Port Maitland. Chapman and Putnam (1984) noted that the Grand may be divided into an upper part where the river and its branches flow mostly in spillways previously formed in till plains, and a lower part where the river has made its own channel across a lake plain.

The main tributaries to the Grand are the Conestoga, Nith, and Speed Rivers. Other notable but smaller tributaries are Fairchild, Whiteman's, McKenzie, Boston, and Big Creeks. The Conestoga River rises northwest of Arthur, drains an area of about 820 km^2, and has a length of about 82 km. The Nith River rises east of the Milverton Moraine, drains an area of about 1,118 km^2, and has a length of about 158 km. The Speed River rises near Orton, drains an area of about 780 km^2, which constitute the main part of the Guelph Drumlin Field, and has a length of about of 60 km.

The Grand River basin contains the Counties of Wellington and Brand, the Regional Municipality of Waterloo, and parts of the Counties of Grey, Dufferin, Perth and Oxford, and the Regional Municipalities of Hamilton-Wentworth, Halton and Haldimand-Norfolk.

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

5.2 LAND USE

The Grand River drainage basin contains a variety of physiographic regions, a diversity of soils, and large differences in climatic conditions. The end result is a large variations in land capabilities and land use. Large areas within the basin are used for the production of row crops, cereal wheat, and specialty crops. Other large areas are devoted to fodder corn, mixed grains, hay, and pasture to raise beef animals, hogs, sheep, and poultry. Woodland, forests, idle lands, and wetlands are also found within the basin.

The four cities of Kitchener-Waterloo, Cambridge, Guelph, and Brantford are the largest urban areas within the Grand River basin and contain residential, commercial, and industrial land use types. These cities dominate the commerce of a large part of southwestern Ontario and they are connected with a dense network of roads and highways where large amounts of road salt are being applied during the winter. Other important urban centres include Arthur, Ayr, Caledonia, Drayton, Dundalk, Elmira, Elora, Fergus, Grand Valley, New Hamburg, Paris, and Wellesley.

5.3 GROUNDWATER USE

There are 26,323 records on file with the Ministry of the Environment for wells constructed in the Grand River basin. Of these, 12,666 wells were constructed within the bedrock, 9,796 in the overburden, and the remaining are of unknown type. The majority of the wells are used to meet the needs of rural domestic supplies and livestock watering.

Groundwater is the most important source for municipal water supplies within the Grand River basin. The megalopolis area of Kitchener-Waterloo, Cambridge and Guelph in the central part of the basin is the largest urban area in the province that depends almost exclusively on groundwater for municipal supplies. In addition, there are other small communities in the basin that depend wholly on groundwater for their domestic, commercial and industrial needs. These communities are Arthur, Ayr, Baden-New Hamburg, Caledonia, Dundalk, Elmira-St. Jacobs, Elora, Fergus, Kitchener-Waterloo, Maryhill, Milverton, Paris, Plattsville, Rookwood, and St. George.

5.4 PHYSIOGRAPHY

According to Chapman and Putnam (1984), parts of ten physiographic regions are found within the Grand River basin. These regions include the Dundalk Till Plain, Stratford Till Plain, Hillsburgh Sandhills, Guelph Drumlin Field, Waterloo Hills, Horseshoe Moraines, Oxford Till Plain, Mount Elgin Ridges, Norfolk Sand Plain, and Haldimand Clay Plain.

The Dundalk Till Plain physiographic region is a gently fluted till plain which forms the headwaters of the Grand, Maitland, Nottawasaga, and Saugeen Rivers. The plain is characterized by poor drainage and swamps, bogs, and depressions are common. The chief urban centres on the plain within the Grand River basin are Dundalk, Grand Valley, and Arthur.

The Stratford Till Plain physiographic region extends as a strip south of Grand Valley and Arthur in the Grand River basin to Stratford and London within the Thames River basin. Within the Grand River basin, the plain has a faint knoll and sag relief and is covered by ground moraine which is interrupted by a few terminal moraines. The plain is drained by the Conestoga and Nith Rivers, tributaries of the Grand.

Within the Grand River basin, the Hillsburgh Sandhills physiographic region extends on the south-eastern flank of Dundalk Till Plain from the basin's topographic divide to an area located to the west of Belwood. The region consists of a moraine which is characterized by a rough topography and sandy materials. The Grand River cuts through this moraine at Belwood where the Shand Dam was constructed. West of Belwood the moraine is smaller and the sand gradually gives way to boulder clay.

The Guelph Drumlin Field physiographic region extends between the Hillsburgh Sandhills in the north and the Paris Moraine to the southeast. The region contains approximately 300 drumlins of all sizes. The drumlins, which are associated with the Lake Ontario Lobe, are characterized by their oval shape and long axes that point due west or northwest. The intervening low ground between the drumlins is largely occupied by gravel terraces and swampy valleys in which the Speed and Eramosa Rivers flow. The main urban centres within this region are Guelph, Fergus, and Elora.

The Waterloo Hills physiographic region is located chiefly within the Regional Municipality of Waterloo but extends into the eastern part of the Township of Blanford-Blenheim, and North Easthope in Perth County. The hills are composed mainly of sand or sandy till while others are kames or kame moraines, with outwash sands occupying the intervening hollows. Adjoining the hilly region is an extensive area of alluvial terraces of the Grand River spillway system. A number of kettle lake and swamps occur in this region. The twin cities of Kitchener-Waterloo and the City of Cambridge are the main urban centres within this physiographic region.

A small area to the southwest of the Waterloo Hill is part of the Oxford Till Plain which extends over most of Oxford County. The plain is composed of calcareous loam till. Also, a small area of the Mount Elgin Ridges physiographic region is within the Grand River basin and is wedged between the Oxford Till Plain to the northwest and the Norfolk Sand Plain to the east and southeast. Two small watersheds within these ridges are drained by the Kenny Creek and the Homer Creek, both tributaries of the Grand.

The Norfolk Sand Plain physiographic region within the Grand River basin is a part of a larger wedge-shaped plain that extends from Lake Erie northward to Brantford on the

Grand River. The plain is composed of sands and silts that were deposited as a delta in glacial Lakes Whittlesey and Warren. Brantford is the main urban center within this region.

The Horseshoe Moraines physiographic region within the Grand River basin is a part of a horseshoe shaped morainic system lying around the upland between Lake Huron, Lake Ontario, and Georgian Bay. Part of the eastern arm of the horseshoe-shaped system is within the basin extending as a strip in a southwesterly direction along the Guelph Drumlin Field and Waterloo Hills and through the Norfolk Sand Plain from the basin's divide near Acton to the basin's divide southwest of Paris. The region is hilly and contains numerous gravel terraces.

The lower portions of the Grand River basin are part of the Haldimand Clay Plain physiographic region which extends westward to the Niagara River. The plain is covered mostly by clay and silt which were deposited when the area was submerged in glacial Lake Warren. The Grand River has cut a deep valley in the clay and silt below Brantford. To the east and west of Caledonia and Cayoga, a number of drumlins are scattered over the plain.

5.5 BEDROCK TOPOGRAPHY AND GEOLOGY

Most of the bedrock within the Grand River basin is obscured by the overburden. In the western parts of the basin, the overburden is generally thick whereas in the eastern parts of the basin it is thin and bedrock outcrops are extensive revealing a rough, gently-sloping surface. Outcrops of the Guelph and Lockport-Amabel dolomites can be seen between Hayesland and Sheffield and also occur along Fairchild Creek, Speed River, and Grand River between Galt and Preston. Also, a low-relief bedrock outcrop, known as the Onondaga Escarpment, occurs in the lower parts of the basin to the east of Hagersville.

The bedrock surface has a regional slope from about 500 m (a.s.l.) in the northern parts of the basin to less than140 m (a.s.l.) near Lake Erie (Figure Gr-1). Superimposed on the regional slope are many rises and hollows, the most notable of these are the buried valleys. Many of the buried valleys, particularly the larger ones, appear to be abandoned valleys of earlier water courses. By far the most prominent of these is the Dundas Valley, the lower portion of which extends from southwest of Dundas to south of Burlington. The valley was probably cut by an earlier Grand River and deepened by glacial action. A prominent valley, probably the ancestral Speed River, can be traced from east of Eramosa south to the Reformatory where it jogs southwest and joins the Eramosa River at Victoria Street in Guelph. The valley was probably cut by an earlier Grand River and deepened by glacial action. Also, the Elora-Fergus Valley was identified north of Kitchener-Waterloo.

The Grand River basin is underlain by Paleozoic formations of Ordovician, Silurian, and Devonian age which extend as belts trending almost in north-south direction. The formations consist predominantly of dolomite and limestone with some shale and chert and have a gentle dip westward toward the Michigan Basin. These formations have been classified as Queenston, Whirpool, Manitoulin, Cabot Head, Amabel-Lockport, Guelph, Salina, Bass Island, Oriskany, Bois Blanc, Amherstburg-Onondaga in order of decreasing age from east to west (Sanford 1969; Sibul et al. 1980; Thurston et al.1992).

The rocks of the Queenston Formation of Upper Ordovician age are the oldest rocks in the basin. These rocks consist of red shale and mudstone and are exposed within a small area in the Dundas Valley west of Hamilton. The Whirpool (sandstone), Manitoulin (dolomite), and Cabot Head (shale) Formations of the Cataract Group of Lower Silurian age overlie the Queenston Formation and also outcrop in the Dundas Valley.

The grey to dark brown dolomites of the Amabel-Lockport Formations of Middle Silurian age occurs in the extreme eastern portions of the basin. The Amabel Formation is the northwards equivalent of the Lockport Formation and is distinguished from it by the presence of numerous reef structures. Overlying the Amabel Formation and extending under most of the eastern parts of the basin is the Guelph Formation of Middle Silurian age. The Guelph Formation consists of cream-colored crystalline dolomite. The Salina Formation of upper Silurian age underlies a large portion of the western half of the basin and consists of dolomite, limestone, and shale.

Overlying the Salina Formation, are the dolostones of the Bass island Formation of Upper Silurian age. The formation subcrops as a narrow band in the extreme western parts of the basin. The Oriskany Formation of Lower Devonian age subcrops within a small area in Oneida and North Cayuga Townships. Overlying the Bass Island Formation with unconformity are the limestones of the Bois Blanc Formation of Middle Devonian age.

The next younger rocks that subcrop in the extreme western portions of the basin are those of the Amherstburg-Onondaga Formations of Middle Devonian age. The Onondaga Formation consists of limestone and the Amherstburg Formation consists of dolomite. The bedrock geology, as mapped by Sandford (1969), is given on Figure Gr-2.

5.6 OVERBURDEN THICKNESS AND GEOLOGY

The Grand River basin has been subjected to glaciation by four different ice lobes which acted independently or in pairs at various times. The lobes involved were the Huron Lobe from the west, the Georgian Bay Lobe from the northwest, the Ontario Lobe from the east, and the Erie Lobe from the southeast. These ice lobes left during their advances and retreats an overburden consisting of glacial, glaciofluvial and glaciolacustrine deposits. The land forms associated with these deposits include ground moraines, end moraines, and drumlins. Parts of a number of end moraines have been identified in the basin. They vary from rough, hummocky accumulations of gravelly till and sand, to gently rolling ridges of silty till. The most important of these are Galt, Waterloo, Breslau, and Paris moraines. Also, numerous drumlins have been identified within the basin and over 300 drumlins have been identified in the Guelph area alone.

5.6.1 Overburden Thickness

The overburden thickness is thin on non-existent in areas where the bedrock outcrops at the surface. Such bedrock outcrops occur along the Fairchild Creek, the Spencer Creek, the Speed and Elora Rivers, the Grand River between Galt and Preston, and at the Elora Gorge in the Elora-Fergus area. In these areas lenses and pockets of drift are seldom more than 5 m thick. In general, the thickness of the overburden increase from east to west. Areas where the overburden thickness is less than 30 m are found in the upper parts of the basin within the Dundalk Till Plain physiographic region, in the east-central parts of the basin within the Guelph Drumlin Field physiographic region, and in the lower parts of the basin mainly within the Haldimand Clay Plain physiographic region. Thick overburden deposits are found within the Waterloo Hills physiographic region. The thickness of these deposits range from 50 to over 110 m (Figure Gr-3).

5.6.2 Glacial Deposits

A number of tills have been identified within the Grand River basin, all are believed to be Wisconsinan, and mostly Late Wisconsinan in age. From oldest to youngest, they are known as the "Lower Beds", Canning Till, Pre-Catfish Creek tills, Catfish Creek Till, Stirton Till, Maryhill Till, Tavistock Till, Port Stanley Drift, Mornington Till, Stratford Till, Wartburg Till, Elma Till, Wentworth Till, and Halton Till. A simplified map of the surficial geology is given on Figure Gr-4.

According to Karrow (1987), the "Lower Beds" unit, which consist mainly of silt till and some sand and gravel, includes all the unclassified sediments below the Canning Till. These beds occur along the Nith River. Also, parts of some of the lower beds of sections near Kitchener probably are of similar age. The beds were tentatively considered to be of early Wisconsinan age.

The Canning till is a nearly pebble-free, silty clay or clayey silt till. It is known to be exposed only in sections along the Nith River and possibly the Grand River (Karrow 1987). The Canning Till was also reported in two boreholes drilled in the Waterloo area (Karrow et al. 1993). Similar fine grained till occurs beneath Catfish Creek Till in the Brantford area (Cowan 1975).

Pre-Catfish Creek tills have been identified in a number of boreholes in the Waterloo area where the Catfish Creek Till lies directly on bedrock. The tills range in texture from silty sand till to clayey silt till. (Karrow et al. 1993). Also, on the east side of Belwood Lake, an exposure of possible Catfish Creek Till was found overlying stratified sand containing clayey silt till. This may represent a till older that the Catfish Creek till or it may be a lens within it (Cowan 1976).

The Catfish Creek Till is usually covered by younger deposits and, therefore, has limited exposure at the surface within the upper parts of the basin. Other outcrops of this till occur in deeply eroded sections along the Conestogo, Nith, and Grand Rivers (Cowan 1976 and1979). The till, which is compact, and has a sandy silt texture, has been also encountered in deep wells in the Waterloo area (Karrow 1987). In the Waterloo area, this till is associated with glaciofluvial silt, sand, and gravel (Karrow et al.1993; Cowan 1976,1979). The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Stirton Till, which is associated with Georgian Bay Lobe, has been observed along the Conestogo Valley between Arthur and Drayton and is thought to be limited to the Conestogo watershed area. The till is usually overlain by Tavistock Till and it is a silt to silty clay till which is dark grey to brown in colour. Based on its stratigraphic position, Karrow (1974) assigned Stirton Till to the Port Bruce Stadial and suggested that it may correlate with the Maryhill Till of the Ontario Lobe to the east.

The Maryhill Till is a silty clay to clayey silt till with a low pebble content and a moderate carbonate content. It occurs along the banks of the Grand River, in the parts of some of its tributary streams such as the Laurel Creek, and in the Guelph area along the Breslau Moraine (Karrow 1987). Drilling in the Waterloo area indicates that Maryhill Till overlies the Catfish Creek Till and is associated with glaciofluvial and glaciolacustrine sediments as well as with local tills (Karrow et al. 1993). The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface show extensive sand or gravel deposits at depth.

The Tavistock Till is a silt to a clayey silt till containing about two percent pebbles. It frequently overlies the Catfish Creek Till in the Grand River basin. The Tavistock Till is associated with the Huron-Georgian Bay Lobe and was formerly mapped as the "Northern Till" in the Guelph area (Karrow 1968) and as "Till C" in the Conestogo area (Karrow 1971). Drilling in the Waterloo area indicates that the Tavistock Till directly overlies the Catfish Creek Till where the Maryhill Till is not present. Otherwise, it overlies the Maryhill Till (Karrow et al. 1993). With the exception of a small area along the western boundary of the basin to the southwest of New Hamburg, the geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show sand or gravel deposits at depth.

The Port Stanley Till varies in texture from sandy silt to clayey silt till and is associated with the Ontario-Erie Llobe. The till occurs at the surface within the Guelph Drumlin Field physiographic region. It is also exposed along the Nith River (Karrow 1963; Cowan 1976) and between Ayr, Paris, and the basin's western topographic divide.

The Mornington Till occurs as a thin ground moraine and is considered by some to be an upper member of Tavistock Till (Cowan 1979). The till is a dark grey to grey silty clay till with rare pebbles. It is very similar texturally and lithologically to both the Tavistock and Stirton Tills. Mornington Till outcrops over an area extending between New Hamburg and Milverton and the basin's western boundaries. The till represents a readvance during retreat of the Tavistock ice. Due to its stratigraphic position, Mornington Till has been assigned to the Port Bruce Stadial (Karrow 1974). The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Stratford Till is a strongly calcareous, sandy silt to silt till. The till is associated with the Huron-Georgian Bay Lobe, and occurs as a thin ground moraine sheet along the western boundaries of the basin to the west of Wellesley and New Hamburg. The Stratford Till is commonly overlain by thin deposits of glaciolacustrine silt and clay. The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Wartburg Till is calcareous, silty clay till, which is very poorly sorted and non-stratified. The till is associated with the Huron-Georgian Bay Lobe. The stratigraphic relationships of the Wartburg Till are poorly known. It forms the core of the Milverton moraine and occurs as ground moraine that is largely buried by Elma Till. A very small outcrop of this till is located along the basin's western boundary to the south of Milverton.

The Elma Till is a deposit of the Georgian Bay lobe. It is calcareous silt, sandy silt to clayey silty till. The till occurs as ground moraine along the western boundaries of the basin to the southwest of Dundalk and between Milverton and Drayton. In other locations, the till is overlain by glaciofluvial sand and gravel, glaciolacustrine silt and younger tills. The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Wentworth Till is sandy till and is usually separated from the lower beds by sand and gravel deposits of kame and outwash origin. The till was deposited by the Ontario-Erie Lobe and it forms the Paris, Galt, and Moffat Moraines (Karrow 1987). The till also outcrops as small drumlins in the lower parts of the basin. The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Halton Till occurs as low-relief ground moraine along the topographic divide north west of Hamilton and, also, in small areas in the lower parts of the basin. Halton Till is predominantly a silt till.

5.6.3 Sand and Gravel Deposits of Glaciofluvial and Glaciolacustrine Origin

Large areas within the Grand River basin are covered with sand and gravel deposits of glaciofluvial or glaciolacustrine origin. The most extensive sequences of these deposits occur throughout most of the Regional Municipality of Waterloo and in Wellington, Brant and Oxford Counties.

The glaciofluvial deposits are associated either with ice-contact stratified drift or with outwash plains and meltwater channels. The ice-contact stratified drift consists primarily of glaciofluvial sediments but may contain lacustrine sediments and till locally. They are characterized by great variability, collapse features, and hummocky topography. Kames, eskers, and end moraines are considered ice-contact deposits.

Kames are found between Doon and Centreville, northwest of Glen Morris, east of Fergus, and southeast of Guelph. Extensive kame sands with some gravels also occur in the Easthope, Waterloo, and Elmira Moraines. Irregular grain-size, sorting, and bedding, and collapse faults are characteristic features.

According to Sibul et al. (1980), the most extensive surficial deposits of sands and gravels in the basin occur throughout most of the Regional Municipality of Waterloo. The materials, for the most part, compose the Waterloo and Elmira Moraine complexes and consists of poorly to well-sorted kame sands and gravels, with associated outwash channels containing well-sorted, fine to coarse sand and fine to medium gravel. Thicknesses of surficial sands and gravels throughout this area range generally from 5 to 15 m, with deposits of up to 40 m occurring locally in Wilmot, Woolwich and Wellesley Townships.

Three prominent eskers extend obliquely across the Guelph Drumlin Field from the Eramosa Valley to the Grand Valley. Their length varies from 15 to 20 km and their height from zero to nearly 15 m. Several smaller eskers may be seen east of Fergus and within the Paris and Galt moraines (Karrow 1987).

Outwash deposits occur as channel fills, terraces along meltwater channels, sheet sands, and gravelly braided outwash between ridges of ice-contact deposits. The outwash deposits are characterized by level to undulating surfaces marked here and there by stream channels and sometimes by kettles. A large area of outwash deposits within the basin appears to be associated directly or indirectly with the Paris and Galt Moraines. Prominent outwash terraces exist along the Grand and Speed Rivers, and an outwash plain separates the Paris and Galt Moraines between Killean Station and Aberfoyle.

Intimately associated with the outwash deposits are the meltwater channel deposits that are sometimes referred to as spillways. The Grand River channel is the largest present-day stream. The channel originated during the retreat of the Tavistock ice from the Orangeville Moraine. A second channel is about 7 km long and is occupied by a tributary of the Schneider Creek. A third channel came down the Speed River Valley and joined with the Grand River at Preston, as it does today, but then continued southwest to the Nith River valley along a valley now occupied by the Cedar Creek. A fourth channel follows the Conestogo River south of Highway 9. In addition, numerous small channels occur within the Guelph Drumlin Field.

5.6.4 Silts and Clays of Glaciolacustrine Origin

Almost all of the lower parts of the Grand River basin from Brantford to Port Maitland are covered with glaciolacustrine sediments consisting of clay, silt, shallow water sand, beach bars, and near shore deposits. Small areas of stratified silt, with some clay and sand are also found to southeast of Guelph in the Paris-Galt moraine complex. Subsurface occurrences of such sediments are found in three stratigraphic positions along the Conestogo River. The oldest occur between the Catfish Creek and Stirton Tills, the next oldest between The Stirton and Tavistock Tills, and the youngest between the Tavistock and Mornington Tills (Cowan 1979).

5.6.5 Recent Deposits

Alluvial deposits of stratified gravel, sand, and silt, border most of the streams within the basin. In studying the stream valleys, it is difficult to distinguish between those terraces which were formed during glacial time and those which were formed during post-glacial time. Extensive alluvial terraces occur along the portion of the Grand River between Inverhaugh and Bloomingdale.

Swamps and bogs, filled into varying depth by organic soil, peat, and muck and muds are numerous within the basin. The largest swamp is the Beverly Swamp which is found east of the Galt and Moffat Moraines. Smaller swamps are numerous in the basin and are found west of Mill Grove, south of Campbellville, north of Lake Medad, between Ayr and Blair, east of Kitchener, within the belt occupied by the Paris Moraine, and within the outwash in front of the Galt Moraine.

5.7 GROUNDWATER OCCURRENCE IN THE BEDROCK

As indicated earlier, most of the wells in the Grand River basin are bedrock wells. Sibul et al. (1980) indicated that the highest groundwater yields from the bedrock, in excess of 900 l/min, are found in the central, northwestern, and northern parts of the basin, generally corresponding to areas of permeable limestones and dolomites. Guelph, Lockport, and

Amabel Formations of Middle Silurian age and the Salina Formation of Upper Silurian age are the most productive and the most widely used bedrock aquifers within the basin. Due to their limited extent within the basin, the Bass Island and Bois Blanc Formations which are highly productive are not widely used as sources of water supply.

According to Turner (1976), the Amabel, Lockport and Guelph Formations constitute a high-capacity aquifer in the Niagara Peninsula and in the area between Hamilton and Owen Sound. The permeability of the Amabel, Lockport and Guelph aquifer is highly variable and it is due primarily to presence of fractures and the chemical dissolution of the upper few metres of dolomites. Most domestic wells obtain adequate water supplies with penetrations of less than 3 m and the potential for developing high-capacity wells in the aquifer is good.

Sibul et al. (1980) indicated that domestic supplies can be obtained readily throughout the Amabel, Lockport and Guelph Formations; and high-capacity, municipal wells that tap the formations provide water supplies for the cities of Cambridge, Guelph and many other smaller towns. Areas containing highest well yields, outside of the major urbanized areas, are located in the vicinity of the Towns of Fergus-Elora, Arthur and Dundalk, and in the Townships of Puslinch, Erin, Amaranth and East Luther.

According to Sibul et al.(1980), the depths of wells in the Amabel, Lockport and Guelph Formations are variable, depending on the overburden thickness. Generally, most of the domestic wells obtain water from the upper 15 m of the aquifer, while municipal and some industrial wells penetrate the bedrock to depths of 30 to 188 m.

Singer et al.(1997) selected a sample of 6,516 wells constructed within the Amabel Formation in southern Ontario to determine the transmissivity distribution for the formation. The minimum and maximum transmissivity values for the sample were estimated to range between 0.1 and 7,550 m^2/day, respectively. The 10 and 90 percentile values were estimated to range between 1.54 and 134.80 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be about 15.5 m^2/day.

A second sample of 1,662 wells was selected by Singer et al.(1997) to determine the transmissivity distribution for wells completed in the Lockport Formation. The minimum and maximum transmissivity values were estimated to range between 0.1 and 1,880 m^2/day, respectively. The 10 and 90 percentile values were to range between 1.69 and 141.00 m^2/day, respectively, and the geometric mean of the second sample's transmissivity distribution was estimated to be about 21 m^2/day.

A third sample of 6,072 wells was selected by Singer et al.(1997) to determine the transmissivity distribution for wells completed in the Guelph Formation. The minimum and maximum transmissivity values were estimated to range between 0.1 and 5,720 m^2/day, respectively. The 10 and 90 percentile values were estimated to range between 1.4 and 105 m^2/day, respectively, and the geometric mean of the third sample's transmissivity distribution was estimated to be about12 m^2/day.

According to Singer et al.(1997), the transmissivity values determined for the Amabel, Lockport and Guelph Formations indicate that the water-yielding capabilities of the three formations are highly variable, which is most likely a reflection of the variable distribution of the fissure systems within the formations. Nevertheless, the 10 and 90 percentile values for the transmissivity distributions of the three samples are within similar range.

Given the large number of wells in the above three samples, Singer et al.(1997) assumed that the transmissivity distributions for the three samples are representative of the water-yielding capabilities of the Amabel, Lockport and Guelph Formations. The relatively high values of the geometric means of the three distributions suggest that the water-yielding capabilities of the three formations are good.

Sibul et al.(1980) described the Salina Formation as a high-capacity, water-supply source north of Kitchener-Waterloo. The authors also reported on substantial fracturing within the formation that was encountered in two test holes located south of Kitchener. Mud circulation could not be maintained in both test holes after approximately 1m of penetrating the bedrock. According to Sibul et al.(1980), the fracturing at both test holes is indicative of the high permeability of the Salina Formation.

Singer et al.(1997) identified a sample of 2,994 wells constructed within the Salina Formation in southern Ontario to determine the transmissivity distribution for the formation. The depths of these wells vary considerably due to large variations in overburden thickness. Once through the overburden, however, the wells penetrate generally less than 15 m into the Salina Formation. The minimum and maximum transmissivity values were estimated to range between 0.1 and 10,200 m^2/day, respectively. The 10 and 90 percentile values were estimated to range between 3 and 190 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be 28 m^2/day.

Given the large number of wells in the sample, Singer et al.(1997) assumed that the sample's transmissivity distribution is representative of the water-yielding capability of the Salina Formation. The relatively high value of the distribution's geometric mean suggests that the formation has a very good water-yielding capability.

A sample of 739 water wells was within the Bass Island Formation in southern Ontario by Singer et al.(1997) to determine the transmissivity distributions for the wells within the unit. The minimum and maximum transmissivity values were estimated to range between 0.4 and 14,220 m^2/day, respectively. The 10 and 90 percentile values were estimated to range between 5 and 180 m^2/day, respectively, and the geometric mean of the transmissivity distribution was estimated to be 31 m^2/day. Given the large number of wells in the sample, Singer et al.(1997) assumed that the sample's transmissivity distribution is representative of the water-yielding capability of the Bass Island Formation. The relatively high value of the distribution's geometric mean suggested that the unit has a very good water-yielding capability.

A sample of 1,069 water wells was selected within the Bois Blanc Formation in southern Ontario by Singer et al.(1997) to determine the transmissivity distributions for the wells within the unit. The minimum and maximum transmissivity values were estimated to range between 0.4 and 3,900 m^2/day, respectively. The 10 and 90 percentile values were estimated to range between 6 and 275 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be 40 m^2/day. Given the large number of wells in the sample, Singer et al.(1997) assumed that the sample's transmissivity distribution is representative of the water-yielding capability of the Bois Blanc Formation. The relatively high value of the distribution's geometric mean suggests the unit has an excellent water-yielding capability.

Data related to short-term pumping tests are available for 10,615 bedrock wells in the basin. The data indicate that 3,114 wells (29.3%) have specific capacities ranging from 1 to 5 l/min/m (Figure Gr-5), 4,713 wells (44.4%) have specific capacities between 5 and 25 l/min/m (Figure Gr-6), 1,208 wells (11.4%) have specific capacities between 25 and 50 l/min/m (Figure Gr-7), and the remaining 1,583 wells (14.9%) have specific capacities larger than 50 l/min/m (Figure Gr-8). These figures indicate that the Guelph, Lockport, Amabel, and Salina Formations are the major groundwater sources within the Grand River basin.

5.8 GROUNDWATER OCCURRENCE IN THE OVERBURDEN

Of a total of 26,323 well records on file with the Ministry of the Environment, 9,796 records (37%) are for wells completed in the overburden. This indicates that the overburden is a significant source of groundwater within the Grand River basin.

High water yielding deposits of extensive sands and gravels are found at different depths and locations within the basin. Sibul et al. (1980) identified a number of such deposits (aquifers), including:

- A sequence of fine to coarse sands and gravels (3 to 10 m thick and 15 to 50 m deep) extends from southern Waterloo Township through much of North Dumfries Township to Ayr.
- A sequence of fine to coarse gravels occurs at depths between 35 to 53 m in the vicinity of Ayr.
- A sequence, confined by lacustrine clays and till(s), of medium to coarse sands and gravels of outwash origin (8 to 9 m thick and 25 to 35 m deep) occurs to the east of the City of Cambridge.

S A sequence of basal outwash sands and gravels (about 6 m thick and 18 to 27 m beep) extends along the Grand River northeast of Paris.

S Permeable deposits, possibly contained in kame materials and inter-layered with till(s), occur in the vicinity of Elmira.

S Sequences of sand and gravel up to 25 m thick occur in the immediate vicinity of Elmira.

S Fine to medium sand, confined by tills and inter-glacial sediments, occur in the vicinity of St. Clements.

S Sand and gravel deposits inter-layered with till occur at varying depths above basal deposits between the Towns of Milverton and Wellesley.

S Complex sequences of inter-glacial materials (5 to 20 m thick) occur throughout much of Waterloo Township and are thickest west of Kitchener-Waterloo and in the vicinity of Baden.

S Medium sands and gravels at depths of 38 to 68 m occur in South Dumfries Township.

S Gravel deposits (3 to 6 m thick and 20 to 65 m deep), overlain by a complex of sediments consisting of fine sands, silts, clays and tills, occur to the north of St. George.

S Sand and gravel deposits overlain by clay (about 3 m thick and 17 to 40 m deep) occur south of St. George; and

S Several sand and gravel deposits (5 to 7 m thick and 5 m to 50 m deep) of relatively limited lateral and vertical extent occur west and northwest of Paris, west of Brantford, in the area southeast of Victoria Mills, and near Cayuga and north of Dunnville.

Data related to short-term pumping tests are available for 6,762 overburden wells in the basin. Of these,1,065 wells (15.7%) have specific capacities ranging from 1 to 5 l/min/m (Figure Gr- 9), 3,156 wells (46.7%) have specific capacities between 5 and 25 l/min/m (Figure Gr-10), 1,145 wells (16.9%) have specific capacities between 25 and 50 l/min/m (Figure Gr-11), and the remaining 1,396 wells (20.7%) have specific capacities larger than 50 l/min/m (Figure Gr-12).

5.9 SUGGESTED BEDROCK MONITORING AREAS

Figure Gr-13 shows the locations of bedrock wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for groundwater monitoring in the bedrock. The susceptibility of groundwater to contamination in these areas was determined based on information related to well yields, bedrock geology, and the thickness and type of overburden materials above the bedrock (Figures Gr-14).

Areas where groundwater in the bedrock is highly susceptible to contamination are defined as those where the bedrock is either near or at the surface or is covered by highly permeable sand and/or gravel deposits. Areas where the bedrock is moderately susceptible to contamination are defined as those where the overburden above the bedrock contains clay or clay till deposits that are less than 3 m in thickness. Areas where the bedrock has low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, six areas (A, B, C, D, E, and F) are proposed for groundwater monitoring within the bedrock. Groundwater susceptibility to contamination within areas (A) and a part of area (E) is high, within areas (B, D, and F) and a part of area (E) is low, and within area (C) and the remaining part of area (E) is variable (Figure Gr-15).

Area (A) is underlain by the Bass Island, Oriskany and Bois Blanc Formations; areas (B and C) are underlain by the Salina Formation; area (D) is underlain by the Bois Blanc and Bass Island Formations; Area (E) is underlain by the Amabel, Lockport, and Guelph Formations; and area (F) is underlain by the Salina, Bass Island, Bois Blanc, and Amherstburg-Onondaga Formations.

Area (A) is located in the lower part of the basin along the southwestern topographic divide, Area (B) extends between Caledonia and the southwestern topographic divide, Area (C) extends from Paris and Brantford in the northeast to the southwestern topographic divide, Area (D) is located along the western topographic divide and to the west of area (C), Area (E) extends along the northeastern part of the basin from Brantford to Dundalk, and Area (F) is located in the northwestern part of the basin.

5.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Gr-16 shows the locations of overburden wells within the Grand River basin which have specific capacities over 50 and 250 l/min/m. It also shows the boundaries of suggested areas for groundwater monitoring within the overburden. Two areas have been identified within the Grand River basin for monitoring groundwater in the overburden . The first area, which has been *highly recommended* for groundwater monitoring within the overburden, is characterized by a large number of wells with high specific capacities (Figure Gr - 16). Some of these wells have specific capacities between 50 and 250 l/min/m and the others have specific capacities of more than 250 l/min/m. The second area, which was *recommended* for monitoring, has many wells with specific capacities over 50 l/min/m.

Groundwater within the suggested areas has a high, variable, or low susceptibility to contamination. The susceptibility of groundwater to contamination in these areas was determined based on information related to well yields, overburden geology, and the thickness and type of overburden materials (Figures Gr-17 and Gr-18).

Areas where the shallow overburden aquifers are highly susceptible to contamination are defined as those where sand and/or gravel deposits are either near or at the surface. Areas where shallow overburden aquifers are moderately susceptible to contamination are defined as those where the sand and/or gravel deposits are covered by clay or clay till deposits that are less than 3 m in thickness. Areas where the overburden aquifers have low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination varies from low to high.

5.11 HISTORICAL MONITORING WELLS

Fifteen bedrock wells, 16 overburden wells, and two wells of unknown type were used in the past for monitoring groundwater in the Grand River basin. The types and locations of these wells are as follows:

S	Well No. 32	An overburden well, 36 m deep, and located in Waterloo County.
S	Well No. 33	An overburden well, 18.3 m deep, and located in Waterloo County.
S	Well No. 34	A bedrock well, 112.7 m deep, and located in Waterloo County, City of Kitchener.
S	Well No. 35	A bedrock well, 59.74 m deep, and located in Waterloo County, City of Kitchener.
S	Well No. 46	An overburden well, 10.7 m deep, and located in Dufferin County within Concession 4, Lot 29.
S	Well No. 59	A bedrock well, 61.57 m deep, and located in Waterloo County, City of Kitchener.
S	Well No. 64	A bedrock well, 30.5 m deep, located in Haldimand County within the lower part of the basin.
S	Well No. 82	An overburden well, 39.6 m deep, and located in

		Waterloo County, City of Kitchener.
S	Well No. 116	An overburden well, 29.6 m deep, and located in Waterloo County.
S	Well No. 117	An overburden well, 41.45 m deep, and located within Waterloo County.
S	Well No. 124	An overburden well, 9.75 m deep, located in Brant County within Concession 1, Lot 2.
S	Well No. 131	A bedrock well, 42.06 m deep, and located in Wellington County.
S	Well No. 213	An overburden well, 3.35 m deep, and located in Wellington County.
S	Well No. 247	An overburden well, 36.9 m deep, and located within Waterloo County.
S	Well No. 372	An overburden well, 9.45 m deep, and located in Oxford County within Concession 10, Lot 8.
S	Well No. 395	An overburden well, 15.24 m deep, and located in Waterloo County within Concession 12, Lot 29.
S	Well No. 396	A bedrock well, 66.75 m deep, and located in Waterloo County.
S	Well No. 397	A bedrock well, 19.8 m deep, and located in Wellington County, Concession 9, Lot 4.
S	Well No. 432	An overburden well, 32 m deep, and located in Wellington County within Concession 4, Lot 4.
S	Well No. 437	A bedrock well, 15.24 m deep, and located in Halton Region, Concession 1, Lot 26.
S	Well No. 438	A bedrock well, 25.9 m deep, and located in Halton Region, Concession 7, Lot 31.
S	Well No. 439	An overburden well, 15.54 m deep, and located in Halton Region, Concession 1, Lot 24.
S	Well No. 440	A bedrock well, 9.44 m deep, and located in Wellington County within Concession 5, Lot 1.
S	Well No. 443	A bedrock well, 17.68 m deep, and located in Halton Region, Concession 4, Lot 26. Piezometers 444, 445, 446, and 447 are within the well.
S	Well No. 514	An overburden well, 15.54 m deep, and located within Waterloo County.
S	Well No. 524	An overburden well, 9.75 m deep, and located within Waterloo County.
S	Well No. 532	A bedrock well, 67.36 m deep, and located in Wellington County, Concession 5, Lot 8.
S	Well No. 535	an overburden Well, 12.19 m deep, and located within Waterloo County.
S	Well No. 536	A bedrock well, 84.43 m deep, and located in Wellington County, Concession 11, Lot 16.

S	Well No. 537	A bedrock well, 108.5 m deep, and located in Wellington County, Concession 1, Lot 11.
S	Well No. 544	A bedrock well, 82.6 m deep, and located in Wellington County, Concession 7, Lot 7.
S	Well no. 560	A well of unknown type, 13.1 m deep, and located in Haldimand County, Concession 9, Lot 9.
S	Well No. 561	A well of unknown type, 13.72 m deep, and located close to well No. 560.

Figure Gr-19 shows the locations of the historical monitoring wells and Appendix I gives the geographic coordinates of these wells.

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FIGURES

Key Map - Gr	A transparency to be used with other figures for orientation purposes.
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CHAPTER SIX

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE HOLLAND AND BLACK RIVER BASINS

By

S.N. Singer, A. Price, and C. K. Cheng

6.1 LOCATION

The Holland and Black River drainage basins are located in southern Ontario between latitudes 43^0 56' and $44^0$21' N and longitudes 79^0 48' and $79^0$12' W. The basins, which cover about 1,046 km^2 , are bounded on the north by Lake Simcoe, on the east by the Pefferlaw Brook watershed, on the south by the Oak Ridges Moraine, and on the west by the Nottawasaga River basin.

The main tributary basins are the Holland River basin (596 km^2), the Black River basin (334 km^2), the Moskinonge River basin (54 km^2), and a number of small catchments draining directly into Lake Simcoe (62 km^2). Large swamp areas occur in the north toward Lake Simcoe in both the Black River and Holland River basins. The most famous of these areas is the Holland Marsh which is a topographic depression extending from the Lake Simcoe to the Oak Ridges Moraine. The Holland and Black River basins include parts of the Regional Municipalities of Simcoe, York, and Durham.

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

6.2 LAND USE

The Holland Marsh to the southeast of Bradford has been drained since 1935 and is considered one of the best producing vegetable areas in Ontario. The Marsh has been put into such crops as onions, lettuce, celery, spinach, carrots, potatoes, and other vegetables. The produce is shipped to Toronto markets and to other parts of Canada.

Good farming areas are also found near Bradford and Newmarket. The cropping pattern in these areas is made up of hay, pasture, grain corn, barley, mixed grain, winter wheat, silage corn, and oats. Dairying, beef cattle, and poultry are the mainstays of many farms.

Low swampy areas are found directly south of Cook's Bay to the north of Holland Marsh.

Long and wide swampy areas that extend for several kilometers are also found along the valleys of the Black River and its tributaries, the Zephyr and Mount Albert Creeks.

About one third of the basin is barren land and another one fifth is in forests. The major urban centers within the Holland and Black River basins are Newmarket and Aurora. Other smaller centers include Bradford, Holland Landing, Keswick, Mount Albert, Sharon, Schomberg, and Sutton.

6.3 GROUNDWATER USE

The total number of wells within the Holland and Black River basins with predetermined geographic coordinates and topographic elevations and on file with the Ministry of the Environment is 9,034. Of these, 637 (7%) are bedrock wells, 8,145 (90%) are overburden wells, and the remaining 3% are of unknown type.

Ground water in the basins adequately supports water supplies for both private domestic and large municipal and industrial water systems. In addition, groundwater is an important source of water supply for market gardening, sod turf production, golf course irrigation, and recreation.

Most of the population within the basins is served by municipal water supply systems and the remaining population is serviced by private water wells. Large capacity wells serve municipal demands for the urban centers of Aurora, Bradford, Holland Landing, Keswick, Mount Albert, Newmarket, and Sharon.

To date, except for localized water-level interference incidents, there have been no apparent problems in supplying all large capacity water demands from groundwater sources. One area within the basins, which is heavily committed to high-capacity wells, is located in the vicinity of the towns of Aurora and Newmarket. These two communities make up the high growth area in the basins, where the future development of groundwater for municipal supplies is considered desirable. Also, the other smaller communities will continue to rely on groundwater.Therefore, the protection and proper utilization of groundwater cannot be overestimated in the context of the overall water management in the basins.

Nitrate concentrations were determined in 60 samples taken in a synoptic survey of general groundwater quality in 1977 and 1978. Subsequently, 62 additional samples were taken in 1978 and analyzed for nitrate and specific conductance in order to define areas of high nitrate levels. Nitrate levels in over 30% of the total of 122 samples exceeded the drinking water objective of 10 mg/L as N (Vallery et al.1982).

High concentrations of nitrates were found in the headwater areas of the Black River and along the height of land north and west of Bradford. High nitrate levels were common in both shallow and deep wells in the headwater areas of the Black River. In the Bradford area, on the other hand, high concentrations of nitrate were found almost exclusively in shallow wells. According to Vallery et al.(1982), the reasons for the high concentrations of nitrate are likely attributable to agricultural activity carried out in the two areas.

6.4 PHYSIOGRAPHY

The physiography of the Holland and Black River basins is a direct result of the deposition and erosion processes during glacial and post-glacial times. According to Chapman and Putnam (1984), parts of three major physiographic units are found within the basin. These regions are the Oak Ridges Moraine, the Schomberg Clay Plains, and the Simcoe Lowlands.

A distinctive topographic feature in the basins is the Oak Ridges Moraine, which forms the height of land at the southern boundary. By and large, the moraine is composed of sandy or gravely materials which are covered in places with till deposits. The surface is hilly with a knob-and-basin relief typical of end moraine with elevation in places is as much as 365 m (a.s.l.). The Moraine contains numerous small lakes and closed depressions or kettles, of which Musselman Lake, at an elevation of about 325 m (a.s.l.) is the largest.

The Schomberg Clay Plains are deep deposits of stratified clay and silt found in two large areas around Schomberg and Newmarket within the Holland and Black River Basins. The surface under the clay is that of a drumlinized till plain. Some of the larger drumlins are exposed through the clay. Since the rolling relief of the underlying till plain has not entirely been eliminated, these areas are not so flat as many lake plains. In the area along the Holland River between Newmarket and Holland Landing considerable dissection has taken place giving rise to rough topography. The Schomberg sediments are typically varved clays composed of about 50% clay and 40% silt behaving mostly as silt. The average depth of the clay deposit seems to be about 5 m, but deep deposits are known (Chapman and Putnam 1984).

Chapman and Putnam (1984) called the lowlands bordering Georgian Bay and Lake Simcoe as the Simcoe Lowlands physiographic region. Lake Simcoe and the lowlands surrounding it and lying between 218 and 260 m (a.s.l.) are part of this physiographic region. From the southern end of Lake Simcoe, known as Cook Bay, a broad valley extends southwestward for about 25 km between high morainic hills. Once a shallow extension of the lake, the floor of this valley is now a marsh of 20,000 acres through which the Holland River meanders sluggishly to Lake Simcoe. The rich organic soil of this area is used for market gardening. A low, swampy, sandy plain extends south of Lake Simcoe and is being drained by the Black River and the Pefferlaw Brook. Extending upstream along these two streams and their tributaries are long swampy valleys which may be considered as the southern extensions of this physiographic region.

6.5 BEDROCK ELEVATION AND GEOLOGY

The bedrock topography within the Holland and Black River basins displays a prominent depression which generally follows the trend of the Holland River Valley (Figure Ho-1). Bedrock surface elevations in the depression range from about 90 to 120 m (a.s.l.). The elevation of the bedrock increases towards the east and reaches about 215 m (a.s.l.) in the northeastern corner of the basins. Similarly, the bedrock elevation increases toward the west and reaches about 180 m (a.s.l.) in the southwestern corner of the basins. A prominent bedrock high south of Aurora at the southern basins boundary has a local relief of about 60 m above the adjoining valley.

The Palaeozoic bedrock in the basins consists primarily of limestone and shale of Middle and Upper Ordovician age. Young Quaternary deposits overlie most of the Palaeozoic rocks. Four formations have been identified within the basins, the Verulam, Lindsay, Blue Mountain, and Georgian Bay Formations (Figure Ho-2).

The Verulam Formation is the oldest formation in the basins and is limited to one area located just south of Cook's Bay and another area located north of Keswick along the eastern shores of Cook's Bay. The formation, which ranges in thickness from 32 to 65 m, is a member of the Simcoe Group and it is of Middle Ordovician age. It consists of fossiliferous limestone with inter-beds of calcareous shale (Thurston et al.1992).

Overlying the Verulam Formation is the Lindsay Formation which extends from the northeastern corner of the basins toward its southwestern corner and covers parts of the Townships of Georgina, East Gwillimbury, West Gwillimbury, and King. The formation, which consists mainly of limestone, is Middle Ordovician age and it is a member of the Simcoe Group (Thurston et al. 1992).

The Blue Mountain Formation (formerly the Whitby Formation) overlies the Lindsay Formation and has a sharp contact with it. The formation, which is Upper Ordovician in age, is present in the southeastern and southeastern corners of the basins. It consists of a blue-grey, poorly fossiliferous, non-calcareous shale up to 60 m thick (Thurston et al. 1992).

The Georgian Bay Formation of Upper Ordovician age is present in the southwestern end of the basins and has a gradational contact with the underlying Blue Mountain Formation. It consists of a blue-grey shale with minor siltstone and limestone inter-beds and ranges in thickness from 125 to 200 m (Thurston et al. 1992).

6.6 OVERBURDEN THICKNESS AND GEOLOGY

In general, the overburden thickness increases from the northwestern corner of the basins where it ranges between 10 and 30 m to the southern parts of the basins where it ranges between 100 and 200 m. Overburden deposits of more than 150 m thick are also found between Bradford and the basins topographic divide near Deerhurst (Figure Ho-3).

The overburden materials consist of glacial, glaciofluvial, and glaciolacustrine deposits of late Wisconsinan age and organic deposits of muck, peat and marl of recent age. Four different tills were identified within the basins, Newmarket Till, Kettleby Till, Halton Till, and undifferentiated Till Unit 19 (Figure Ho-4).

The Newmarket Till was deposited by the Simcoe Lobe during the later part of the Port Bruce Stade. The till is a calcareous silt to sandy silt til. It outcrops along the basins western topographic divide and forms most of the high rim surrounding the Holland Marsh. (Barnett 1992).

The Kettleby Till represents a southerly advance of the Simcoe Lobe to the Oak Ridges Moraine during Port Huron Stade. The till is highly calcareous silty clay to clay till. It occurs over the northern flank of the Oak Ridges Moraine in the south western part of the basins and also to the east of Aurora and Newmarket (Barnett 1992).

The Halton Till was deposited by the Erie-Ontario Lobe during the Port Huron advance. The till is primarily a sandy silt to silt till. It covers a small area over the northern flank of the Oak Ridges Moraine in the southeastern part of the basins (Barnett 1992).

Small areas along the northern and eastern parts of the basins are covered with sandy silt to silt till which was mapped as Unit 19 on Map 2556 of the Quaternary geology of Ontario. According to Barnett (1992), the till was deposited during the Two Creeks Interstade.

Large areas along the southern and southeastern boundaries of the basins are covered with stratified sand and gravel of glaciofluvial origin. Sediments of glaciolacustrine origin are also widespread throughout the basin. These sediments were deposited in glacial Lakes Schomberg and Algonquin.

Lake Schomberg was formed within a small area between the receding Lake Simcoe Lobe and the Oak Ridges Moraine. The lake left behind some small sand deposits between Happy Valley and kettleby and extensive stratified to varved silt and clay deposits to the west and east of Holland Marsh. Lake Algonquin followed Lake Schomberg and occupied the Lake Simcoe basin as well as parts of Lake Huron and Lake Michigan basins. Lake Algonquin left behind extensive sand deposits within the valleys of the Holland and black Rivers.

Fluvial silt, sand and gravel deposits are found at the surface along the northwestern and eastern topographic divides Peat and muck deposits are found to the south of Cook's Bay, and within the flood plains of the Holland and Black Rivers and their tributaries.

6.7 GROUNDWATER OCCURRENCE IN THE BEDROCK

Most of the bedrock wells are located in areas where the overburden is relatively thin or does not include water bearing sand or gravel deposits. This is particularly true in the northern and central parts of the basins where the overburden is underlain by the Lindsay and Verulam Formations. Some 580 wells penetrate the Lindsay Formation, 32 wells penetrate the Verulam Formation, 20 wells penetrate the Blue Mountain Formation, and 5 wells penetrate the Georgian Bay Formation.

Singer et al.(1997) identified 28,172 water wells within all the formations of the Simcoe Group which were treated together as one hydrogeologic unit in southern Ontario. Of these wells, a sample of 6,414 wells was selected to determine the transmissivity distribution for the hydrogeologic unit. The minimum and maximum transmissivity values were determined to range from 0.05 to 3,062 m^2/day, respectively, and the geometric mean was estimated to be 5.7 m^2/day. The water-yielding capability of the Simcoe Group was described as being fair.

Singer et al.(1997) treated the Blue Mountain and Georgian Bay Formations as one hydrogeologic unit. The authors identified 2,130 wells within the unit in southern Ontario. Of these, a sample of 1,293 wells was selected to determine the transmissivity distribution for the unit. The minimum and maximum transmissivity values for the sample were determined to range from 0.06 to 1,194 m^2/day, respectively, and the geometric mean of the sample's transmissivity values was estimated to be 2.9 m^2/day. The water yielding-capability of the Blue Mountain-Georgian Bay unit was described as being poor.

Specific capacity data are available for 382 bedrock wells within the basin. Of these, 191 wells (50%) have specific capacities less than 5 l/min/m (Figure Ho-5), 139 wells (36%) have specific capacities between 5 and 25 l/min/l (Figure Ho-6), 21 wells (5 %) have specific capacities between 25 and 50 l/min/m (Figure Ho-7), and 31 wells (8%) have specific capacities higher than 50 l/min/m (Figure Ho-8). Based on the distribution of wells on Figure Ho-8, it is possible to conclude that the limestones of the Lindsay Formation are the best bedrock water-yielding formation within the Holland and Black River basins.

The relatively low specific capacity values for wells within the four bedrock formations in basin are consistent with the findings of Singer et al.(1997) for southern Ontario. Compared to the overburden, the bedrock within the Holland and Black River basins is not an important source of groundwater.

6.8 GROUNDWATER OCCURRENCE IN THE OVERBURDEN

Most wells in the basins are drilled or bored in overburden and usually satisfy domestic water-supply demands. Vallery et al. (1982) noted that groundwater is obtained from a number of discrete water-bearing overburden sediments that are not in most cases continuous over large areas, but rather occur as individual lenses that have limited extent. For this reason, the term "aquifer complex" was used to describe water-bearing sediments that have similar elevations and piezometric levels. Seven such aquifer complexes were identified within the basins, including the Alliston, Algonquin, Holt , Kame Outwash, Mount Albert, Oak Ridges, and Schomberg Aquifer Complexes (Vallery et al. 1982).

The Oak Ridges and Kame Outwash Aquifer Complexes in the southern part of the basins, and the Algonquin Aquifer Complex in the northeastern part of the basins are the major water-bearing sediments occurring at elevations above 215 m (a.s.l.). Water yields from wells in the three complexes are adequate to support domestic water requirements, and high yields are common in the Oak Ridges Aquifer Complex.

The Oak Ridges Aquifer Complex consists of permeable sands and gravels which outcrop at the surface or occur at depth between layers of less permeable clay, silt, and till deposits. The Kame Outwash Complex consists mainly of sand and minor amounts of gravel at elevations above 240 m (a.s.l.). The Algonquin Aquifer Complex consists of shallow lenses of sand and gravel in tills. The permeable lenses are often thin and isolated, and their water yields are limited.

The Schomberg Aquifer Complex in the west and the Holt Aquifer Complex in the east consist of buried sands and gravels at elevations between 205 and 245 m (a.s.l.). Individual well yields in these two complexes are variable, and are generally adequate to support domestic water supplies. Several wells within the Holt Aquifer Complex have estimated yields of up to 30 l/sec and one municipal well in the Schomberg Aquifer Complex serves the community of Schomberg and yields up to 38 l/sec.

International Water Consultants Ltd. (1991) described an aquifer zone of sand and gravel deposits within the East Holland River subwatershed which occur at an elevation range of 180 to 260 m (a.s.l.). This aquifer zone, which was called the Intermediate Aquifers, overlaps the range of the Holt Aquifer Complex identified by Vallery et al. (1982).

Hunter et al. (1996) described an aquifer complex, which they named the Lowland Aquifer Complex, that occurs in the general elevation range from 200 to about 260 m (a.s.l.). The elevation range of this aquifer complex overlaps the elevation ranges of the Holt Aquifer Complex identified by Vallery et al. (1982) and the Intermediate Aquifers zone identified by International Water Consultants Ltd. (1991). According to Hunter et al. (1996), the Lowland Aquifer Complex includes sandy meltwater channel deposits which extend up gradient into the tunnel channels that cut into and through the Newmarket Till. It also extends under the moraine as deep channel deposits fanning out into the regional lowlands as discrete aquifer units between elevations from about 220 to 240 m (a.s.l.).

Hunter et al. (1996) noted that many rural settlements on the lower slopes adjacent to the Oak Ridges Moraine depend on this aquifer for potable water supply. In addition, a number of golf course irrigation wells and a number of municipal production well fields are also located in the aquifer system.

Information related to the transmissivity of the Intermediate Aquifers has been reported in a number of hydrogeologic investigations. According to International Water Consultants Ltd. (1991), a number of municipal wells have been developed in the Intermediate Aquifers zone, including Newmarket Wells 9 and 14. The reported transmissivities for these wells are generally moderate and in the order of 100 to 400 m^2/day.

The Alliston and Mount Albert Aquifer complexes are found at elevations between 110 and 220 m (a.s.l.). The Alliston Aquifer Complex consists of a series of primarily fine to coarse-grained sand lenses which yield up to 90 l/sec in a number of municipal wells in the vicinity of Aurora and Newmarket. The Mount Albert Aquifer Complex consists primarily of deep sands and gravels averaging about 3 m in thickness. Well yields are generally good with one municipal well serving the community of Mount Albert and rated at 45 l/sec (Vallery et al. 1982).

It appears that the Alliston Aquifer Complex which was identified by Vallery et al. (1982) and described by Turner (1977) is the same as the Yonge Street Aquifer that generally follows Yonge Street from Aurora to Holland Landing and then swings to the northeast. The name for the aquifer is widely used locally and reflects the fact that the aquifer extends for a distance along Yonge Street which is a famous landmark in southern Ontario. The aquifer is found at elevations between110 and 200 m (a.s.l.) and consists of a series of primarily fine to coarse-grained sands and gravels. The sands and gravels are thicker and coarse-grained in the aquifer core and become thinner and finer towards the flank areas to the east and west.

International Water Consultants Ltd. (1991) described a lower aquifer along the Yonge Street core which ranges in elevation from 150 to 200 m (a.s.l.), and they also described another aquifer in the Bradford and Holland Marsh area which appears to range in elevation from 110 to 180 m (a.s.l.). Where the two aquifers overlap, the Bradford aquifer occurs below the Yonge Street Aquifer which indicates that the two aquifers are separate. According to International Water Consultants Ltd. (1991), the Yonge Street Aquifer is a channel deposit which trends generally in a north-south direction and appears to be loosely associated with bedrock valleys.

Hunter et al. (1996) indicated that bounded, channel aquifers occur at elevations below 180 m (a.s.l.) at many locations within the Oak Ridges Moraine and up to150 m (a.s.l.) or deeper south of the moraine. These aquifers, which they named the "Bounded Channel

Aquifer Complex" include the deep well fields at Aurora and Newmarket. Further, the authors suggested that the Yonge Street Aquifer is a member of the Bounded Channel Aquifer Complex. Pumping tests of wells that tap water from the aquifer indicate that it is about one kilometer wide in Aurora area and it exhibits strong proximal boundaries.

Information related to the transmissivity of the Yonge Street Aquifer has been reported in a number of hydrogeologic investigations. According to International Water Consultants Ltd. (1991), testing of York Region municipal wells indicated local that transmissivities within the Yonge Street Aquifer core that range from about 1,000 m^2/day in the Newmarket area up to about 4,000 m^2/day in the Holland Landing and Sharon/ Queensville areas.

Data related to short-term pumping tests are available for 4,466 overburden wells. The data indicate that 2,185 wells (49%) have specific capacities ranging from 1 to 5 l/min/m (Figure Ho-9), 1,765 wells (39.5%) have specific capacities between 5 and 25 l/min/m (Figure Ho-10), 264 wells (5.9%) have specific capacities between 25 and 50 l/min/m (Figure Ho-11), and the remaining 252 wells (5.6%) have specific capacities larger than 50 l/min/m (Figure Ho-12).

Figure Ho-12 indicates that high-capacity water wells occur mainly within four areas in the basins. One area is located within Georgina Township and extends from Beverly Hills on Cook's Bay to the eastern topographic boundary of the basins east of the Zephyr Creek. A large number of high capacity wells in this area are located along Cook's Bay between Beverly Hills and Keswick.

A second area is located mainly within the headwaters of the Black River, and the Mount Albert and Vivian Creeks extending from the basins divide in the east to a point between Newmarket and Holland Landing in the west. A large number of the high-capacity wells in this area are located to the east and south of Mount Albert.

A third area extends along the headwaters of the Holland River drainage basin from Musselman Lake in the east through Aurora, Happy Valley, and Lloydtown in the west. The area includes parts of the Oak Ridges Moraine and the Schomberg Clay Plains. Most of the high capacity wells in this area are located between Musselman Lake and Wesley Corners. A forth small area is located in the western parts of the basin around Coulson's Hills.

6.9 SUGGESTED BEDROCK MONITORING AREAS

Figure Ho-13 shows the locations of bedrock wells with specific capacities of over 25 l/min/m and the boundaries of suggested areas for monitoring of groundwater within the bedrock. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials above the bedrock (Figure Ho-14).

Areas where groundwater in the bedrock is highly susceptible to contamination are defined as those where the bedrock is either near or at the surface or is covered by highly permeable sand and/or gravel deposits. Areas where the bedrock is moderately susceptible to contamination are defined as those where the overburden above the bedrock contains clay or clay till deposits that are less than 3 m in thickness. Areas where the bedrock has low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on this definition, four areas (A, B, C, and D) are suggested for groundwater monitoring in the bedrock. The susceptibility of groundwater to contamination within area (A) ranges from moderate to variable; whereas it is low within areas (B), (C), and (D) due to the presence of over 15 m of clay material protecting the bedrock (Figure Ho-13).

Area (A) is located in the northern part of the basins in the vicinity of Jackson's Point on Lake Simcoe. It is underlain by the Lindsay Formation and many well logs reveal the presence of sands and/or gravels with clay deposits of less than 3 meters in thickness over the bedrock. Areas (B) and (C) are also underlain by the Lindsay Formation. Area (B) covers parts of the Black and Maskinonge Rivers watersheds, while Area (C) is centered in the Holland Marsh. Monitoring within areas (B and C) would provide information about ambient groundwater conditions within the Lindsay Formation and reveal the impacts, if any, of past agricultural chemical use.

To monitor the ambient groundwater conditions within the Verulam Formation, a monitoring well is recommended for Area (D). Although the susceptibility of groundwater to contamination in Area (D) is low, a growing population and an increasing number of septic tanks may affect the groundwater quality.

No groundwater monitoring is recommended for the Georgian Bay or the Blue Mountain Formations because of the following three reasons. First, these two formations have a small percentage of the total wells used in the area. Secondly, the formations produce minimal quantities of water. Third, groundwater in the formations has extremely low susceptibility to contamination due to the extensive thickness of the overburden above the bedrock.

6.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Ho-15 shows the location of overburden wells with specific capacities of more than 50 l/min/m, and the boundaries of areas where groundwater within the overburden has a high, low or variable susceptibility to contamination. Data related to well yields and the geology of overburden were used to determine the susceptibility of groundwater to contamination in these areas (Figure Ho-16).

Areas where the shallow overburden aquifers are highly susceptible to contamination are defined as those where sand and/or gravel deposits are either near or at the surface. Areas where shallow overburden aquifers are moderately susceptible to contamination are defined as those where the sand and/or gravel deposits are covered by clay or clay till deposits that are less than 3 m in thickness. Areas where the overburden aquifers have low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, four areas (E, F, G, and H) are proposed for groundwater monitoring in the overburden. The susceptibility of groundwater to contamination within Area (H) is variable and within areas (E, F, and G) are mainly low. However, parts of the later three areas have either high or variable susceptibility to contamination. Although monitoring of groundwater is recommended within areas (E, F, and G), it is highly recommended within the portions of these areas that are highly susceptible to contaminations.

Area (E) extends between the southern topographic divide and a line extending roughly from part of the basin from Musselman Lake through Newmarket and Lloydtown in the west. Area (F) extends from the eastern topographic divide through the middle parts of the black River watershed and further to the northern part of Holland Marsh. Area (G) extends between the northeastern boundaries of the basins and a line extending from Keswick to Cedarbrae. Area (H) is located to northwest of Holland Marsh in the vicinity of Coulson's Hill.

6.11 HISTORICAL MONITORING WELLS

One bedrock well and 11 overburden wells were used in the past for monitoring groundwater in the Holland and Black Rivers drainage basin. The types and locations of these wells are as follows:

Well No. 147	An overburden well, 2.75 m deep, and located in York County, Concession 6, Lot 26.
Well No. 340	An Overburden well, 8.84 m deep, and located in York County, Concession 5, Lot 34.
Well No. 341	An Overburden well, 17.07 m deep, and located in York County, Concession 3, Lot 29.

Well No. 342	An overburden well, 92.96 m deep, and located in York County, Concession 2, Lot 19.
Well No. 343	An overburden well, 3.66 m deep, and located in York County, Concession 3, Lot 9.
Well No. 344.	An overburden well, 3.35 m deep, and located in York County, Concession 1, Lot 121.
Well No. 527	An overburden well, 3.96 m deep, and located in York County, Concession 7, Lot 17.
Well No. 528	An overburden well, 4.27 m deep, and located in York County, Concession 5, Lot 26.
Well No. 568	An overburden well, 99.06 m deep, and located in York County, Town of Aurora.
Well No. 569	An overburden well, 99.06 m deep, and located in York County, Town of Aurora, Concession 1, Lot 86.
Well No. 570	An overburden well, 117.35 m deep, and located in York County, Town of Newmarket, Concession 1, Lot 96.
Well No. 571	A bedrock well, 137.16 m deep, and located in York County, Town of Newmarket.

Figure Ho-17 shows the locations of the historical monitoring wells and Appendix I gives the geographic coordinates of these wells.

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FIGURES

Key Map - Ho	A transparency to be used with other figures for orientation purposes.
Figure Ho - 1	Bedrock topography in the Holland and Black River drainage basins.
Figure Ho - 2	Bedrock geology in the Holland and Black River drainage basins.
Figure Ho - 3	Overburden thickness in the Holland and Black River drainage basins.
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Figure Ho - 5	Bedrock wells with specific capacities equal to or less than 5 l/min/m.
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Figure Ho -13	Suggested areas for monitoring groundwater in the bedrock.
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CHAPTER SEVEN

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE MOIRA RIVER DRAINAGE BASIN

By

S.N. Singer, C.K. Cheng, and G. Soo Chan

7.1 LOCATION

The Moira River drainage basin is located in eastern Ontario between latitudes 44° 57' and 44°09' N and longitudes 76°58' and 77° 40' W. Elevations in the basin vary between about 80 m (a.s.l.) in the south and about 400 m (a.s.l.) in the extreme north, but most of the land is in the range of 150 to 300 m (a.s.l.). Local relief rarely exceeds 50 m.

The headwaters of the Moira River rise in the rocky highlands of the Counties of Hastings, and Lennox and Addington about 88 km north from Lake Ontario. The river and its major tributaries, Skootamatta, Black, and Clare Rivers, and the Parks Creek, drain about 2,745 km^2. The Skootamatta and Black Rivers combined drain about 40 per cent of the basin; Clare River and the Parks Creek drain another 20 per cent, and the remaining 40 per cent is drained by the Moira River and its smaller tributaries. Many lakes occur within the upper parts of the basin; the largest being Skootamatta, Lingham, Moira and Stoco Lakes.

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

7.2 LAND USE

Industry and agriculture form the economic base in the southern third of the basin, while tourism, recreation, and logging are the major activities in the north where 80 per cent of the area is woodland. The area south of Thomasburg and the area bounded by Queensborough, Madoc, Malone and Kellers Bridge are the only areas in the basin where the soils are suitable for general agricultural use. Approximately 40 per cent of this area is cultivated, and dairying, beef production, and mixed farming account for more than 90 per cent of the agricultural operations.

Public recreation facilities in the basin are provided in conservation areas and municipal parks. The Moira River Conservation Authority operates seven park areas in the basin. Several tourist camps, used primarily for fishing, are located on Moira, Stoco, and

Skootamatta Lakes. Also, several stream sections are used for boating, canoeing, and fishing.

The major population centres within the basin are Belleville, which is located at the mouth of the Moira River, and the villages of Tweed, Madoc and Deloro.

7.3 GROUNDWATER USE

Groundwater is used in the basin for rural domestic purposes, and to meet municipal, industrial, agricultural, and recreational water supply needs. Most of the rural population lives in the southern parts of the basin and most of their water needs is obtained from groundwater sources, with only a small percentage being obtained from surface water sources. Water use in the northern parts of the basin is small because rural settlement is sparse and generally restricted to hamlets along main highways. Most domestic water supplies are obtained from rock wells that supply adequate amounts of water for domestic use.

The total number of water wells within the Moira River drainage basin that have geographic coordinates on file with the Ministry of the Environment is 3,549. Of these wells, 430 (12.1 %) are overburden wells, 2,921 (82.3 %) are bedrock wells, and the rest are of unknown type. All the overburden wells are located within the lower parts of the basin.

Four municipalities have communal water-supply systems: Belleville, Tweed, Madoc and Deloro. Belleville's water supply is obtained from the Bay of Quinte. Two municipal wells provide water supply to Tweed, another two wells provide water supply to Madoc, and one well provides water supply to Deloro. Most industries in the basin are not served by municipal water supply systems, but obtain their supplies from individual wells.

The most common water-related problem in the Moira River basin is inadequate water supply. Inadequate ground-water supplies for domestic wells are frequent in the limestone areas of the basin, and the quantities of water obtainable in the Precambrian rock areas are unpredictable. The inadequacy of water supplies is sometimes compounded by well interference, poor natural groundwater quality, and pollution of existing supplies.

4.4 PHYSIOGRAPHY

The northern two-thirds of the basin is characterized by Precambrian bedrock topography of the Canadian Shield, while the southern one-third of the basin is characterized by thin overburden on Palaeozoic limestones. The overburden on Precambrian bedrock is thin or absent, and for the most part, the land terrain has rock-and-knob topography. Overburden land forms are limited to occasional kame mounds, esker ridges, and sand plains formed by sediment accumulation in bedrock depressions. Swamp and bog deposits fill numerous bedrock lows and surround many lakes (Sibul et al.1974).

Chapman and Putnam (1984) identified three physiographic regions within the souther one-third portion of the basin, the Napanee Plain, the Peterborough Drumlin Field, and the Dummer Moraines.

The Napanee Plain physiographic region within the lower portion of the basin is part of a larger region extending along the northen shores of the Bay of Quinte between Belleville and Kingston. It is a flat to undulating plain of limestone from which the glaciers stripped most of the overburden.

The Peterborough Drumlin Field physiographic region within the basin is part of a larger region extending from Hastings County in the east to Simcoe County in the west. Within the basin, this physiographic region contains numerous drumlins. The drumlins are composed of calcareous till and the general orientation of the drumlin axes is from northeast to southwest. A few eskers are also found in the region.

The Dummer Moraines physiographic region within the basin extends as a belt between the Peterborough Drumlin Field in the south and the Canadian Shield to the north. The underlying bedrock consists of limestones. A discontinuous limestone cuesta, usually less than10 m high, defines the contact between the Precambrian plutonic rocks and the Palaeozoic limestones in areas east, south and west of Stoco Lake.

The moraines within this region are characterized by angular fragments and blocks of limestone with many Precambrian rocks also present. The surface is extremely rough even though most of the morainic ridges are quite low. Several tributaries to the Moira River cross this morainic belt. Most of them follow pre-glacial valleys, entrenched up to 30 m in the bedrock. A number of these valleys are blocked by glacial drift, thus creating long narrow lakes or swamps. The Moira and Stoco Lakes are prominent examples of this type.

7.5 BEDROCK TOPOGRAPHY AND GEOLOGY

Precambrian rocks underlie the whole of the Moira River drainage basin and are in turn overlain in the south by approximately 105 m of Palaeozoic limestone. Thin and discontinuous overburden deposits cover the southern edge of the Precambrian rocks and become thicker and more continuous over the Palaeozoic rocks in the south.

The bedrock elevation within the basin ranges from about 75 m (a.s.l.) in Belleville at the mouth of the Moira River to between 300 to 400 m (a.s.l.) in the headwater areas. The bedrock surface of the Precambrian rocks exhibits a rock-and-knob terrain which is characterized by low relief. The Palaeozoic rocks, on the hand, exhibit a gently sloping relief with elevation ranging between 75 m and 180 m (a.s.l.) and they control to a large extent the configuration of the present land surface topography in the lower one-third of the basin (Figure Mo-1).

A bedrock valley extends from the Clare River Valley through Stoco Lake to the lower reaches of the Moira River. Another bedrock valley can be traced along the Parks Creek Valley. The Clare River Syncline is a pronounced bedrock feature in the east-central portion of the basin where differential erosion of metamorphic rocks has produced a parallel drainage system (Sibul et al.1974).

The Precambrian rocks consist of plutonic, metasedimentary, and metavolcanic rocks. These rocks outcrop in the northern two-third of the basin and are part of the Canadian Shield. The plutonic rocks consist of granite, syenite, diorite, gabbro, anorthosite, and amphibolite; the metasedimentary rocks consist of paragneiss, pellitic schists and gneisses, marble, and para-amphibolite; and the metavolcanic rocks consist of basic volcanics, greenstone, and pillow lava.

The Palaeozoic rocks in the southern part of the basin are of Middle Ordovician age. These rocks belong to the Shadow Lake Formation of the Basal Group and the Gull River, Bobcaygeon, Verulam and Lindsay Formations of the Simcoe Group. The Shadow Lake Formation separates the Palaeozoic rocks from the older Precambrian rocks. Outcrops of this formation have been found at a number of locations along the eastern boundaries of the basin at McGuire Settlement. The outcrops consist of red and green shale, sandstone, and arkose. Overlying the Shadow Lake Formation is a series of limestones and shales of the Simcoe Group (Figure Mo-2).

7.6 OVERBURDEN THICKNESS AND GEOLOGY

The overburden within the Moira River drainage basin consists of glacial, glaciofluvial, and glaciolacustrine sediments of Pleistocene age with alluvial and swamp deposits of Recent age. The overburden is missing over most of the northern tow-third of the basin. In most of the other areas the thickness of the overburden is less than10 m. Only in the kame moraine along the southwestern boundary of the basin does the thickness of the overburden increase to reach over 70 m. The moraine is approximately 25 km long and attains a relief of 60 to 90 m above the surrounding land surface (Figure Mo-3).

According to Barnett (1992), the glacial deposits in the basin consist of two tills, Map Unit 19 and Map Unit 20. These tills were deposited by minor oscillations of the ice margin of the Ontario lobe during the Two Creeks Interstadial.

The undifferentiated till of Map 19 is found in the lower parts of the basin extending from the City of Belleville to the vicinity of Roslin and Thresher Corners. The till, which forms a drumlinized till plain, has a sandy silt matrix which is high in carbonate content.

The undifferentiated till Map Unit 20 extends as a belt between the till of Map unit 19 and the Canadian Shield. The till outcrops within Dummer Moraine physiographic region and forms broad, gently undulating plains. In most areas, the till is thin and the ground surface is littered with large limestone and Precambrian boulders. The till itself is extremely stoney, has a sandy matrix, and is high in total matrix carbonate.

The glaciofluvial deposits in the basin consist of sand and gravel.Two esker ridges are prominent in the basin. One is the sand and gravel ridge that trends southwest from Marlbank to just south of Myrehall and the other, which is locally known as the Tweed Esker, is a narrow ridge of sand and gravel prominently displayed on the till plain between Tweed and Zion Hill. In addition, the kame moraine, which extends along the southwestern topographic boundaries of the basin, consists mainly of glaciofluvial deposits of sand and gravel, although till occurs at the surface in some elevated parts of the moraine.

Glaciolacustrine deposits of sand, silt, and clay form low plains drained by the Chrysal and Palliser Creeks, and an extensive but thin cover of clay is found in the plain north and northeast of Honeywell Corners.

Alluvial, peat and muck deposits of Recent age are found in river valleys and swamps (Figure Mo-4).

7.7 GROUND WATER OCCURRENCE IN THE BEDROCK

As indicated earlier, over 82 per cent of the wells in the Moira River drainage basin are bedrock wells and about half of these wells have been drilled in the Precambrian rocks. According to Sibul et al.(1974), most of the Precambrian wells obtain suitable supplies within the upper 15 m of the rock, although deeper wells do occur. The well water yield is a function of the number and size of fractures and joints encountered by a well. Since these openings may begin and end abruptly, follow complex trends, and possess strong directional orientation, well yields do vary considerably from place to place.

Some wells drilled in the Precambrian rocks have reportedly failed to obtain sufficient water for domestic uses, many domestic wells have yields less than 5 liters per minute, and some municipal wells at Deloro, Madoc and Tweed yields in excess of 900 liters per minute. The municipal wells are considerably deeper than most other wells constructed in the Precambrian bedrock. Sibul et al.(1974) indicate that the deep municipal wells are located in areas of relatively complex geology and it is likely that folding and faulting associated with metamorphism have resulted in the development of rechargeable fractures and joints at depth.

Singer et al.(1997) calculated the transmissivity values for a sample of 7,875 wells constructed within the Precambrian rocks in southern Ontario. The geometric mean of the sample's transmissivity values was estimated to be 4.2 m^2/day and the water-yielding capability of these rocks was assessed to be poor.

According to Sibul et al.(1974), the limestones of the Simcoe Group are the most common source of groundwater in the southern third of the basin. Water is obtained from a variety of depths in these rocks but most wells obtain suitable supplies from the upper 10 to 15 m. Yields from wells drilled in the limestones are variable but most are less than 5 liters per minute, which is only marginally adequate for domestic uses. Areas in the basin where well yields are greater than 5 liters per minute usually correspond with bedrock depressions where the overburden is thick and consists of water-bearing sands and/or gravels. Dry wells in the limestone occur randomly in the basin; however, the greatest concentration occurs near Lake Ontario.

Singer et al.(1997) calculated the transmissivity values for a sample of 6,414 wells constructed in the rocks of the Simcoe Group in southern Ontario. The geometric mean of the sample's transmissivity values was estimated to be 5.7 m^2/day and the water-yielding capability of the Simcoe Group was assessed to be fair.

Specific capacity data are available for 1,994 bedrock wells within the Moira River drainage basin. Of these, 835 wells (41.87%) have specific capacities less than 5 l/min/m (Figure Mo-5), 639 wells (32.05%) have specific capacities between 5 and 25 l/min/l (Figure Mo-6), 160 wells (8.02%) have specific capacities between 25 and 50 l/min/m (Figure Mo-7), and 360 wells (18.06%) have specific capacities higher than 50 l/min/m (Figure Mo-8). Based on the distribution of wells on Figure Mo-8, it is possible to conclude that the majority of the high capacity wells in the basin are located either within the Simcoe Group or within the Precambrian rocks.

7.8 GROUNDWATER OCCURRENCE IN THE OVERBURDEN

Sibul et al.(1974) noted that the overburden is a significant source of groundwater supplies only in the southwestern part of the basin. Elsewhere in the south the overburden is relatively thin and consists mainly of glacial till, which is normally a poor source of groundwater. Two main overburden aquifers were identified by Sibul et al.(1974) in the southwestern part of the basin: (1) thick sand and gravel deposits within the kame moraine along the southwestern edge of the basin, and (2) the sand deposits that adjoin this moraine and extend eastward along Chrysal and Palliser Creeks. A third overburden aquifer of sand and gravel is buried directly over the bedrock extending from the southern boundaries of the basin through Honeywell Corners and along Parks Creek.

Specific yields from a number of wells completed in the sands and gravels of the three aquifers exceed 50 l/min/m. However, in spite of these above average values, the specific capacities of most overburden wells are less than 5 l/min/m which indicates that most of the sands and gravels are not extensive and/or are poorly sorted. Water levels in most wells on the moraine are approximately 15 m deep.

Data related to short-term pumping tests are available for 383 overburden wells. The data indicate that 143 wells (37.33%) have specific capacities ranging from 1 to 5 l/min/m (Figure Mo-9), 133 wells (34.73%) have specific capacities between 5 and 25 l/min/m (Figure Mo-10), 42 wells (10.97%) have specific capacities between 25 and 50 l/min/m (Figure Mo-11), and the remaining 65 wells (16.97%) have specific capacities larger than 50 l/min/m (Figure Mo-12).

7.9 SUGGESTED BEDROCK MONITORING AREAS

Figure Mo-13 shows the locations of bedrock wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for monitoring of groundwater in the bedrock. The susceptibility of groundwater to contamination in the selected areas was determined based on information related to the thickness and type of overburden materials above the bedrock (Figure Mo-14).

Areas where groundwater in the bedrock is highly susceptible to contamination are defined as those areas where the bedrock is either near or at the surface or is covered by highly permeable sand and/or gravel deposits. Areas where the bedrock is moderately susceptible to contamination are those areas where the overburden above the bedrock contains clay or clay till deposits that are less than 3 m in thickness. Areas where the bedrock has a low susceptibility to contamination are those where the overburden contains clay or clay till deposits that are much more than 3 m in thickness. Areas where the bedrock has variable a variable susceptibility to contamination are those where the susceptibility changes within different parts of the area from high to moderate or low.

Based on the above definitions, three areas (A, B, and C) are proposed for groundwater monitoring within the bedrock. Area (A) is underlain by Palaeozoic rocks of the Simcoe Group and areas(B and C) are underlain by Precambrian rocks of the Canadian Shield.

Groundwater susceptibility to contamination within Area (A) is variable ranging from high to low and within areas (B and C) it is high. Area (A) is located in the lower part of the basin extending from Bay of Quinte northward to line that joins Lime Lake in the east to Drag Lake in the west. Area (B) extends from Stoco Lake to the vicinity of Madoc. Area (C) is located in the vicinity of Kaladar.

7.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Mo-15 shows the location of overburden wells with specific capacities of over 50 l/min/m, and the boundaries of areas where groundwater within the overburden has a high or a variable susceptibility to contamination. Data related to well yields and the geology of overburden were used to determine the susceptibility of groundwater to contamination in these areas (Figure Mo-16).

Areas where the shallow overburden aquifers are highly susceptible to contamination are defined as those where sand and/or gravel deposits are either near or at the surface. Areas where shallow overburden aquifers are moderately susceptible to contamination are defined as those where the sand and/or gravel deposits are covered by clay or clay till deposits that are less than 3 m in thickness. Areas where the overburden aquifers have low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination area ranges from low to high.

Based on the above definitions, three areas (D, E, and F) are proposed for groundwater monitoring in the overburden. The susceptibility of groundwater to contamination within Area (D) is variable, within Area (E) is mainly high, and within Area (F) is low.

Area (D) covers most of the Palliser Creek watershed and extends through the Moira River Valley to the vicinity of Plainfield. The area is covered with a sandy till and sand and clay deposits of glaciolacustrine origin.

Area (E) extends along the western boundaries of the basin from north of Moira through Halloway and Chatterfon to the headwaters of the Palliser Creek. The area contains a kame moraine which consists mainly of sands and gravels as well as the associated sands that adjoin the moraine along its eastern edge. The thickness of the sands and gravels ranges from 10 to 30 m above the bedrock. However, some well logs within Area (E) indicate the presence of less permeable materials above the sands and gravel.

Area (F) is located to the south of Stoco Lake. The area is underlain by glaciofluvial deposits and sandy till.

7.11 HISTORICAL GROUNDWATER MONITORING NETWORK

Fifteen historical monitoring wells have been identified in the basin. Of these, 12 are in the bedrock and three are in the overburden. The types and locations of these wells are as follows:

Well No. 122	An overburden well, 9.14 m deep, and located in Hasting County, Thurlow Township, Concession 6, Lot 22.
Well No. 123	A bedrock well, 21.95 m deep, and located in Hasting County, Tyendinaga Township, Concession 6, Lot 7.
Well No. 157	An overburden well, 4.27 m deep, and located in Hasting County, Hungerford Township, Concession 3, Lot 5.
Well No. 158	A bedrock well, 18.29 m deep, and located in Hasting County, Hungerford Township, Concession 2, Lot 13.
Well No. 159	A bedrock well, 7.62 m deep, and located in Hasting County,

	Huntingdon Township, Concession 13, Lot 13.
Well No. 161	A bedrock well, 10.97 m deep, and located in Hasting County, Elzevir and Grimsthorpe Township, Concession 4, Lot 3.
Well No. 162	An overburden well, 4.88 m deep, and located in Hasting county, Madoc Township,Concession 3, Lot 6.
Well No. 163	A bedrock well, 12.19 m deep, and located next to Well No. 162.
Well No. 209	A bedrock well, 21.64 m deep, and located in Hasting County, Hungerford Township, Concession 5, Lot 1.
Well No. 210	A bedrock well, 6.71 m deep, and located in Hasting County, Madoc Township, Concession 10, Lot 1.
Well No. 230	A bedrock well, 12.19 m deep, and located in Hasting County, Madoc Township, Concession 5, Lot 28.
Well No. 256	A bedrock well, 57.91 m deep, and located in Hasting County, Thurlow Township, Concession 6, Lot 23.
Well No. 324*	A bedrock well, 59.44 m deep, and located in Hsting County, Hungerford Township, Concession 2, Lot 1. Well contains two piezometers at depths of 17.07 m and 50.90 m.
Well No. 326*	A bedrock well, 13.71 m deep, and located in Hasting County, Hungerford Township, Concession 2, Lot 1.
Well No. 327	A bedrock well, 56.39 m deep, and located in Hasting County, Thurlow Township, Concession 6, Lot 13.
Well No. 554	A bedrock well, 17.68 m deep, and located in Hasting County, Sidney Township, Concession 5, Lot 13.

Figure Mo-17 shows the locations of the historical monitoring wells and Appendix I gives the geographic coordinates of these wells.

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FIGURES

Key Map - Mo	A transparency to be used with other figures for orientation purposes.
Figure Mo - 1	Bedrock topography in the Moira River drainage basin.
Figure Mo - 2	Bedrock geology in the Moira River drainage basin.
Figure Mo - 3	Overburden thickness in the Moira River drainage basin.
Figure Mo - 4	Overburden geology in the Moira River drainage basin.
Figure Mo - 5	Bedrock wells with specific capacities equal to or less than 5 l/min/m.
Figure Mo - 6	Bedrock wells with specific capacities between 5 and 25 l/min/m.
Figure Mo - 7	Bedrock wells with specific capacities between 25 and 50 l/min/m.
Figure Mo - 8	Bedrock wells with specific capacities higher than 50 l/min/m.
Figure Mo - 9	Overburden wells with specific capacities equal to or less than 5 l/min/m.
Figure Mo -10	Overburden wells with specific capacities between 5 and 25 l/min/m.
Figure Mo -11	Overburden wells with specific capacities between 25 and 50 l/min/m.
Figure Mo -12	Overburden wells with specific capacities higher than 50 l/min/m.
Figure Mo -13	Suggested areas for monitoring groundwater in the bedrock.
Figure Mo -14	Panel diagram showing the geologic logs of bedrock wells with specific capacities higher than 50 l/min/m.
Figure Mo -15	Suggested areas for monitoring groundwater in the overburden.

Figure Mo -16 Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 50 l/min/m.

Figure Mo -17 Locations of historical monitoring wells in the Moira River drainage basin.

CHAPTER 8

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE SEVERN SOUND DRAINAGE AREA

By

S. N. Singer and C. K. Cheng

8.1 LOCATION

Severn Sound (to be referred to as the Sound in this chapter) is a group of bays in southeast Georgian Bay. The Sound is located in southern Ontario between longitude 79^{0} 54' and 79^{0} 24' W and latitude 49^{0} 31' and 49^{0} 74' N. The Sound has a total drainage area of about 1095 Km^{2}, a maximum length of about 43 km in a northwest-southeast direction and a maximum width of about 46 Km in a northeast-southwest direction. It is bounded on the north by Severn River basin and Georgian Bay, on the east by Lake Simcoe and Lake Couchiching basins, on the south by the Nottawasaga River basin, and on the west by Georgian Bay as well as by a narrow strip of land that drains into Georgian Bay.

The topography of the Sound is a direct result of the deposition and erosion processes during glacial and post-glacial times. Land surface elevations vary from 177 m above mean sea level (a.s.l.) along the shores of Georgian Bay to 412 m (a.s.l.) in a small area located within the Bass Lake moraine along the southern topographic divide.

The Sound contains six small watersheds draining from the south and a miscellaneous area draining land along the north shore of the Sound. The watersheds are those of the North, Coldwater, Sturgeon and Wye Rivers and the Hog and Copeland Creeks. Due to their small gradients within the flat-floored valleys, the streams have cut shallow channels and their flow at times is very sluggish. These small gradients explain the swampy character of many areas within the valleys.

The North River rises in a hilly plateau to the north of Bass Lake and empties into Matchedash Bay. It has three major tributaries: the Purbrook, Bear and Silver Creeks. The Coldwater River originates near Coulson and flows from south to north before it enters into Matchedash Bay. The Sturgeon River originates in a hilly plateau near Hillsdale and flows in a northerly direction before it empties into Sturgeon Bay. The Hog Creek originates in Medonte Township, flows in a northerly direction through Tay Township, and empties into Hog Bay in Severn Sound. The Wye River originates to the north of the Cook's Hill area in Flos Township and flows from south to north to its outlet into Georgian Bay. The Copeland Creek originates from Lalligan Lake in Tiny Township and flows in a northwesterly direction to its outlet into Penetang Harbour.

Most of the area lies in Simcoe County whereas a small area in the north is within Georgian Bay Township (Baxter Ward) in the District Municipality of Muskoka. As of 1995 a major restructuring of the County of Simcoe municipalities took place. The original thirteen local municipalities represented within the Sound were restructured to form seven municipalities. The old and new municipalities are as follows:

OLD MUNICIPAL STRUCTURE	**NEW MUNICIPAL STRUCTURE**
SIMCOE COUNTY:	
Tiny Township	Tiny Township
Flos Township Village of Elmvale	Springwater Township
Town of Penetanguishene	Town of Penetanguishene
Town of Midland	Town of Midland
Village of Port McNicoll Village of Victoria Harbour Township of Tay	Township of Tay
Township of Medonte Township of Oro	Township of Oro-Medonte
Township of Matchedash Township of Orillia Village of Coldwater	Township of Severn

As many groundwater studies and well records were filed under the old municipal names, they are used throughout the text of this chapter.

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

8.2 LAND USE

The Sound includes the following types of land use:

- woodlots (includes reforested and pastured woodlots),
- intensive agriculture (corn, mixed, grain, and hay systems),
- non-intensive agriculture (pasture and grazing systems),

- row crops (corn and beans),
- specialty crops (field vegetables, market gardens, berries, tobacco, nurseries, and sod farms),
- non-agricultural lands (idle lands, extractions pits, and dumps),
- urban areas (includes recreational lands), and
- organic soils (marshes, bugs, and swamps).

8.3 GROUNDWATER USE

The number of water wells within the Sound has increased steadily from about 200 wells in 1965 to 3,211 wells in 1995. Of these, 1,103 (34. 3%) are bedrock wells, 1,958 (61.0%) are overburden wells and the remaining 150 (4.7%) are of unknown type. Most of the wells (85%) are being used for domestic water supply. The remaining wells are being used for livestock watering, municipal, commercial, industrial, irrigation, cooling, and mixed use purposes.

The following groundwater concerns have been identified within the Sound:

- concerns related to potential groundwater contamination from road de-icing, gasoline service stations, septic systems, closed and open landfill sites, dry cleaning operations, and decommissioning of industrial sites;
- concerns related to mining of groundwater by high capacity water takings (municipal supplies, industrial supplies, golf courses, irrigation, and bottled water);
- concerns related to quantity interference with shallow aquifers by high capacity water takings;
- concerns related to the protection of groundwater recharge areas, wetlands, and susceptible areas to contamination; and
- concerns related to the ownership of groundwater.

8.4 PHYSIOGRAPHY

Chapman and Putnam (1984) identified three physiographic regions in the Sound namely, the Georgian Bay Fringe, the Simcoe Lowlands and the Simcoe Uplands. The Georgian Bay Fringe physiographic region area forms a broad belt bordering Georgian Bay and occupying large parts of Muskoka and Parry Sound. The region occupies an almost continuous strip across the north-eastern parts of the Sound and extends further north along the shorelines of Georgian Bay from Matchedash Bay to Beausoleil Island. A major part of the region was covered by glacial Lake Algonquin and it is characterized by low relief, shallow soil, and bare rock knobs and ridges.

The Simcoe Lowlands physiographic region extends from Georgian Bay to Lake Simcoe.

The surface elevation of this within the Sound ranges from 177 to 250 m (a.s.l.). The region consists mainly of flat-floored valleys, which were flooded by glacial Lake Algonquin. On both sides of the valleys, shore cliffs, beaches and terraces, left during the various stages of glacial Lake Algonquin, can be traced for long distances. The floors of the valleys are covered by glaciofluvial, glaciolacustrine and recent deposits of mud, peat, and muck. In addition, large outcrops of Ordovician limestone are found within the North River watershed and are considered part of the Simcoe Lowlands physiographic region. These strata are generally flat-lying, with a low dip of about 5 meters per kilometre to the southwest (Deane 1950).

The Simcoe Uplands physiographic region consists of a series of broad, rolling till plains separated by steep-sided, flat-floored valleys. The surface elevations within this region range from 250 to 412 m (a.s.l.). Most of the till plains are encircled by numerous shorelines, indicating that they were islands in glacial Lake Algonquin. The till plains occur throughout the central parts of the Sound as well as in the Penetang Peninsula where they were probably submerged in glacial Lake Algonquin.

The Bass Lake Kame Moraine is also considered a part of the Simcoe Uplands physiographic region. The moraine, which consists mainly of sand and gravel with minor amounts of clay or boulders, is located along the south-eastern boundaries of the drainage area and is characterized by rolling, kettle and knob topography.

8.5 BEDROCK TOPOGRAPHY AND GEOLOGY

The topography of the bedrock within the Sound was determined based on the surficial distribution of Precambrian and Palaeozoic rocks and the records of 1,079 water wells and exploration boreholes. Figures Se-1 shows the bedrock elevations within the Sound area. The figure indicates that the bedrock elevations range from over 250 m to less than 120 m (a.s.l.). Highest elevations are found in the northeastern parts of the Sound area where the Palaeozoic rocks are either at or very close to the surface. They are also found within three dome-like structures located immediately north of Bass Lake. The lowest bedrock elevations are found in the southwestern part of the Sound area.

Figure Se-1 also indicates that the Sound contained two major drainage systems before the Quaternary Period. The two systems were separated by a series of dome-like structures that extended in an east-westerly direction immediately to the north of Bass Lake and then continued in a north-westerly direction to Sturgeon Bay. Surface water to the south and south-west of the bedrock ridge drained towards an extensive bedrock valley known as the Laurentian Channel, which extended from Georgian Bay towards Cook Bay on Lake Simcoe and further to Lake Ontario (Singer et al. 1997).

The bedrock in the Sound consists of Palaeozoic sedimentary rocks of Middle and Upper Ordovician age resting on a Precambrian basement (Figure Se-2). Young Quaternary deposits cover most of the Palaeozoic rocks. The Precambrian rocks are mostly obscured by a cover of Palaeozoic and Quaternary deposits. However, these rocks occur at the surface or very close to the surface within a narrow strip that extends along the northern borders of the Sound from Maple Valley in the east to Matchedash Bay in the west, and along the eastern shores of Georgian Bay northward to Honey Harbour and Beausoleil Island.

The Precambrian rocks within the Sound consist mainly of tonalite, granodiorite, monzonite, granite, syenite, gneiss, anorthosite and gabbro. According to Easton (1992), these rocks are part of the Central Gneiss Belt of the Grenville Province which is the youngest part of the Canadian Shield.

A succession of Palaeozoic sedimentary rocks of Middle Ordovician age overlies the Precambrian rocks over most of the Sound. Limestones outcrop at the surface at several locations in Medonte, Orillia and Tay Townships and form a narrow, limestone plain that extends along the southern rim of the Canadian Shield to Port McNicoll on Georgian Bay.

The Palaeozoic rocks belong to the Basal and Simcoe Groups of the Middle Ordovician age. Four formations of Middle Ordovician age have been identified within the Sound area. These formations include the Shadow Lake Formation of the Basal Group and the Gull River, Bobcaygeon, and Verulam Formations of the Simcoe Group (Johnson et al.1992).

The Shadow Lake Formation is the oldest of the Palaeozoic formations within the Sound area. Its contact with the overlying Gull River Formation is commonly gradational and is placed at the first significant carbonate bed (Liberty, 1969). The formation unconformably overlies the Precambrian basement and occurs at surface as a thin, narrow band to the east of Maple Valley and to the north of Carlyon in Orillia Township as well as at Waubaushene in Tay Township. Due to its relative thinnest, the Shadow Lake Formation and overlying Gull River Formation are commonly portrayed as a single unit (Figure Se-2).

The Shadow Lake Formation consists of shale, sandstone, limestone and conglomerate. Its thickness differs from place to place. In Tay, western Matchedash, and Medonte areas, the formation ranges in thickness from 0.0 to 12 m (Derry et al. 1989).

The Gull River Formation is the oldest unit of the Simcoe Group and it conformably overlies the rocks of the Shadow Lake Formation throughout the Simcoe County area. The unit represents deposition within a supratidal to intertidal, flat environment with coarser-grained beds representing storm deposition.

Armstrong and Anastas (1992) tentatively subdivided the Gull River Formation into two informal members, the lower and upper, which approximately correspond to the lower and middle members of Liberty (1969). Within the Sound, the lower member of the Gull River Formation consists of argillous, fine-grained, dolomitic limestones and dolostones; fine-grained, fossiliferous limestones; medium-grained limestones; and micritic to very fine-grained, sparsely to very fossiliferous limestones. The upper member of the Gull River Formation consists of micritic to very fine-grained, sparsely fossiliferous limestone. This upper member is completely exposed in the Medonte and Uhthoff quarries (Armstrong and Rheaume 1993).

The Bobcaygeon Formation overlies the Gull River Formation and it is generally more fossiliferous. The fauna, grain size and sedimentary features of the formation suggest a shallow, subtidal, depositional environment. Liberty (1969) subdivided the Bobcaygeon Formation into three members, lower, middle and upper. The lower member of the Bobcaygeon Formation consists of 6 to 8 m of grey-brown, very-fine- to coarse-grained, moderately fossiliferous limestones. The middle member consists of about 6 m of light to medium brown, fine- to coarse- grained, moderately fossiliferous limestones, which are interbedded with grey-green, calcareous shales. The upper member consists of approximately 10 m of light grey-brown to blue-grey, fine- to coarse-grained, fossiliferous, limestones (Armstrong and Rheaume 1993).

Conformably overlying the Bobcaygeon Formation are the interbedded limestones and shales of the lower member of the Verulam Formation. This unit occurs in a very small area to the southwest of Allenwood in Flos Township where it is covered by a thick mantle of Quaternary deposits. Its distribution in this area has been established from well records (Liberty 1969).

8.6 OVERBURDEN THICKNESS AND GEOLOGY

Most of the bedrock within the Sound area is obscured by a mantle of unconsolidated overburden sediments which were deposited during the Late Wisconsinan Stage of the Quaternary Period. These deposits occur mainly in the Simcoe Uplands and Simcoe Lowlands physiographic regions.

Figure Se-3 shows the spatial distribution of overburden thickness within the Sound area. The figure is based on data obtained from geologic logs of deep boreholes and the records of 1,536 wells. These wells either penetrate the bedrock or are deep overburden wells.To obtain additional accuracy, the surface elevations of those areas where the bedrock outcrops at the surface were also used in the compilation of the figure.

As expected, the thickness of the overburden in areas where the Precambrian and Palaeozoic rocks are at or close to the surface is small and ranges from 0 to less than 20 m. The thickness of the overburden increases gradually along a front extending in an easterly-northwesterly direction. This front extends from areas located to the north of Bass Lake in the east to areas located west of Midland in the northwest.

The maximum thickness of the overburden (120 to over 140 m) is found along an axis that extends from the southern boundaries of the Sound through Orr Lake until it reaches the western boundary. To the southwest of this axis, the overburden thickness starts to decrease to a range of 80 -120 m. Other thick overburden deposits are found within the area of the Bass Lake Kame Moraine. The maximum thickness of the overburden in this area ranges from 80 to 100 m along an axis that extends in a north-southerly direction to the west of Bass Lake.

The overburden deposits within the Sound consist of glacial, glaciofluvial, glaciolacustrine, and recent deposits. The following sections provide brief descriptions of these deposits.

8. 6.1 Glacial Deposits

Most of the glacial deposits within the Sound have a sandy silt to a silty matrix and are commonly rich in clasts. These tills were mapped by Barnett et al.(1991) as "Map Unit 19" on the OGS Map 2556. Other tills, which have a fine-grained, clast poor, predominantly silty clay to silt matrices, outcrop at the surface in a few small locals. These tills were mapped by Barnett (1991) as "Map Unit 21" on the OGS Map 2556.

The tills within the Sound consist of broad rolling plains; ground moraine, and drumlins. The till plains, which formed islands within proglacial Lake Algonquin, are surrounded by abandoned beaches. A thin layer of ground moraine covers the bedrock in parts of the northeastern and northern parts of the Sound. The greater part of the drumlin-field areas, the swales between the drumlins, and the gently rolling hills that are not definite enough to be called drumlins are also classified as ground moraine.

Most of the drumlins within the Sound occur along its eastern boundaries in Orillia Township. A few drumlins occur also in the areas between Sturgeon Bay and Hog Bay, and between Hog Bay and Midland Bay in Tay Township. The drumlins are composed mainly of a till with some stratified sand and gravel on the top, ends, or sides. The orientation of the long axes of the drumlins is northeast to southwest, which reflects most probably the orientation of the ice movement during the last readvance of the glacier (Figure Se-4).

Available data indicate that additional tills occur under the surface within the Sound. Barnett (1991), in a preliminary report on the stratigraphic drilling of Quaternary sediments in Barrie area, Simcoe County, described the geologic logs of 5 deep boreholes drilled in Medonte and Oro Townships. Three of these boreholes (OGS - 90 - 5, OGS - 90 -7 and OGS - 90 -14) reached the bedrock and provide complete profiles of the Quaternary section. Till-like, diamicton materials, separated by thick sequences of gravel, sand, silt and clay, were found at different depths in all the boreholes. The exact number of buried tills within the Sound, however, is not known.

8.6.2 Glaciofluvial Deposits

One of the most important ice-contact deposits within the Sound area is the Bass Lake Kame Moraine, which can be found at or near the surface south of Bass Lake. The moraine, which occupies the southern half of the Sound area and continues beyond its boundaries, is approximately 25 km long with a maximum width of 8 km. The surface elevation of the moraine ranges from about 275 to 412 m (a.s.l.). It is characterized by a hummocky topography with extensive kettles and knolls, tunnel channels, small dunes, and steep ice-contact slopes along its northern boundaries. The material of the moraine is mainly sand and gravel with only minor amounts of clay or boulders, and is water sorted to varying degrees.

Other ice-contact deposits are found to the north of Warminster and south of Fair Valley in the Coldwater River watershed, at various locations within the Sturgeon River watershed, and around Midland Park Lake. These deposits consist of fine to coarse-grained sand, gravelly sand and gravel with minor amounts of silt, clay, and flow till.

A small outwash deposit of well-sorted, fine to coarse-grained sand with minor gravel, silt and clay is found in the headwaters of the Coldwater River adjacent to the Bass Lake Kame Moraine. Other outwash deposits consisting mainly of medium to coarse sand with some boulders occur to the south and north of Orr Lake around earlier "Algonquin Islands", and also west of Midland Park Lake. The Coldwater River, the Hog Creek, and Wye River have cut channels through these outwash deposits.

The origin of the outwash deposits is fluvial or deltaic. As the glacier melted, streams loaded with sediment flowed away and deposited their load of sand and gravel in valleys or in deltas. Compared to the ice-contact deposits, the outwash deposits are generally more uniform. Their texture varies from silt to fine sand to coarse gravel, and their bedding is generally horizontal.

The flat to undulating topography of the outwash deposits has been modified by subsequent actions of Lake Algonquin waters producing boulder strips and some depressions on the surface. According to Burwasser and Boyd (1974), much of the outwash sand between the "Algonquin Islands" in the Orr Lake sheet has been reworked so completely that it is mapped as lacustrine sand. On the edges of the "Islands" and below the Algonquin bluff is a deposit, mapped as winnowed outwash, of medium to fine sand. These sands contain numerous boulders, some exceeding 2 metres in their longest dimension.

8.6.3 Glaciolacustrine Deposits

Extensive deposits of glaciolacustrine origin occur at the surface within the study area. They consist of very fine to medium-grained sand with silt and minor clay. These horizontally bedded deposits are found mainly in the headwaters of the North and Coldwater Rivers, over most of the valley of the Sturgeon River, around Orr Lake, and along the western boundaries of the study area.

The thickness of the glaciolacustrine deposits is highly variable. Within the Precambrian, rock-knob lowlands in the northern parts of the Sound, the deposits are generally thin, but can vary greatly within short distances. In areas, where the Palaeozoic rocks are close to the surface, the deposits are thin and uniform. In other areas, where deep boreholes were drilled in Medonte and Orillia Townships, the total thickness of the glaciolacustrine deposits is over 60 m.

The glaciolacustrine deposits within the Sound include abandoned beaches, sand plains, and clay plains. Abandoned beaches consisting of gravel and sand deposits are found around the "Algonquin Islands" within the Sound. At many places within the Sound, the abandoned beaches are poorly developed, but in many other places, however, one, two or three levels of well-developed beaches can be traced for long distances. These cascading beaches can be found particularly around Orr Lake, along both sides of the valleys of the Hog Creek and Wye River, and to the southwest of Midland Park Lake.

Clay flats of glaciolacustrine origin are most common in the depressions within the Sound, and are found in the middle sections of the North, Coldwater and Sturgeon Rivers and the Hog Creek. These glaciolacustrine clays also cover a large area extending from the south of Wye Marsh to the headwaters of the Wye River. In addition clay deposits that are varved with silt are found in the low central part of the Orr Lake area along the Wye River.

The thickness of the clay deposits vary from place to place. The records of water wells drilled for the Village of Elmvale indicate that the clays in some locations extend to depths of over 38 m. The well records in the vicinity of the Village of Coldwater show that the clay deposits are 6 to 20 m thick. Fine-grained silts and clays, 23 m thick, were also reported in water wells to the south of the Silver Creek Mobile Home Park in Orillia Township.

8.6.3 Recent Deposits

Accumulations of organic matter of mud, peat, muck and marl are found in many low, inadequately drained parts of the study area. The largest such deposits are found in Tiny Marsh, which is located in the southwestern corner of the study area and covers a surface area of about 8 km^2 of open marsh land. Modern alluvium deposits of gravel, very fine to coarse-grained sand, silt and clay occur along stream channels within the study area. These deposits are probably composed of reworked glaciolacustrine sediments.

8.7 GROUNDWATER OCCURRENCE IN THE BEDROCK

Five hydrogeologic units were identified within the bedrock in the Sound (Singer et al. 1996). These units include the Precambrian rocks, and the Shadow Lake-Gull River, Bobcaygeon and Verulam Formations.

From a hydrogeologic point of view, only those Precambrian rocks that are at or close to the surface within the northern parts of the Sound are significant as a source of groundwater supplies. The remaining Precambrian rocks are buried under thick sequences of younger rocks of Palaeozoic and Quaternary ages and, therefore, cannot be tapped for groundwater.

In their study of the hydrogeology of the Sound, Singer et al.(1999) identified 202 wells completed within the Precambrian rocks with short-duration, pumping test data. These data were used to estimate the transmissivity distribution for the wells. Since the availability of fractures and fissures within the Precambrian rocks is depth dependent, two suitable samples that reflect the degree of penetration of these rocks were selected from the available data. The first sample consisted of 87 wells whose depths of penetration are less than 20 m, and the second sample consisted of 125 wells whose depths of penetration are more than 20 m.

The minimum and maximum transmissivity values determined for the first sample were estimated to range from 0.50 to 1,485 m^2/day, respectively, and the geometric mean was estimated to be 5.6 m^2/day. The minimum and maximum transmissivity values for the second sample were estimated to range from 0.06 to 1,552 m^2/day, respectively, and the geometric mean was estimated to be about 1 m^2/day.

Based on the estimated transmissivity values for the two samples, Singer et al.(1999) concluded that the upper 20 m of the Precambrian rocks within the Sound have higher water-yielding capabilities compared to deeper rocks. Further, the low values of the geometric means for the transmissivity distributions of both samples indicate that the Precambrian rocks have a poor water-yielding capability.

The Shadow Lake and Gull River Formations are at or close to the surface within a strip extending from the eastern boundaries of the Sound towards the southern shores of Georgian Bay through to the area's western boundaries. Since it is not possible to distinguish between the two formations in the records of water wells drilled in this strip, the formations were combined into one hydrogeologic unit. Singer et al.(1999) identified 429 wells within the unit with suitable, short-duration data on pumping tests. The data were divided into two samples. The first sample consisted of 301 wells which penetrate the unit for less than 20 m, and the second sample consisted of 128 wells which penetrate the unit for more than 20 m.

The minimum and maximum transmissivity values for the first sample were estimated to range from 0.1 to 3,175 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be about 12 m^2/day. The minimum and maximum transmissivity values for the second sample were estimated to range from 0.05 to1,455 m^2/day, respectively, and the geometric mean of the second sample's transmissivity distribution was estimated to be about 2 m^2/day. Singer et al.(1999) concluded that the probability of finding more water in the Shadow Lake-Gull River hydrogeologic unit is higher within its upper 20 m. Given the relatively small water-yielding capability of the unit, however, it is doubtful that it contains a well-developed system of interconnected solution cavities.

Rocks of the Bobcaygeon Formation overly the rocks of the Gull-River Formation and cover most of the southern parts of the Sound. These rocks are obscured, however, by thick deposits of Quaternary origin. Singer et al.(1999) identified 148 wells within the formation with suitable, short-duration data on pumping tests. The data were divided into two samples. The first sample consisted of 84 wells which penetrated less than 20 m of the unit, and the second sample consisted of 72 wells which penetrated more than 20 m of the unit.

The minimum and maximum transmissivity values for the first sample were estimated to range from 0.25 to 1,696 m^2/day, respectively, while the value of the geometric mean of the transmissivity distribution was estimated to be about 8 m^2/day. The minimum and maximum transmissivity values for the second sample were estimated to range from 0.08 to 703 m^2/day, respectively, while the value of the geometric mean of the second sample's transmissivity distribution was estimated to be about 5 m^2/day. Singer et al.(1999) concluded that the probability of finding more water in the formation is higher within its upper 20 m and that the water-yielding capability of the formation is fair.

The rocks of the Verulam Formation occur within a small locality at the southwestern corner of the Sound. These rocks are buried under thick sequences of Quaternary deposits and no water wells tap the formation. Therefore, from a hydrogeologic point of view, the Verulam Formation is of little significance as a source of groundwater within the study area.

8.8 GROUNDWATER OCCURRENCE IN THE OVERBURDEN

In general, the availability of groundwater in the overburden ranges from poor to good. Most wells in the overburden are used to meet domestic supplies and livestock watering requirements. Locally, overburden aquifers are the most productive sources of groundwater within the Sound and provide a number of urban areas with water supplies.

A large number of wells are completed in areas where till deposits outcrop at the surface within the Sound. Singer et al.(1999) identified a sample of 710 such wells that have short-term data related to pumping tests and estimated their transmissivity distribution. The minimum and maximum transmissivity values for the sample were estimated to range from 0.3 to15,784 m^2/day, respectively, and the geometric mean of the sample was estimated to be about 45 m^2/day.

Singer et al.(1999) also identified a sample of 117 wells with data related to short-term pumping tests. The wells are completed in areas where ice-contact deposits outcrop at the surface. The pumping test data were used to determine the transmissivity distribution for the sample. The minimum and maximum transmissivity values were estimated to range from 1 to 10,526 m^2/day, respectively, and the geometric mean was estimated to be 126 m^2/day.

A sample of 124 wells completed in outwash deposits have suitable data related to short-term pumping tests. Singer et al.(1999) used these data to determine the transmissivity distribution for the sample. The sample's minimum and maximum transmissivity values were estimated to range from 0.2 to 1,937 m^2/day, respectively, and the geometric mean was estimated to be about 65 m^2/day.

A sample of 383 wells completed in glaciolacustrine sand and gravel deposits have suitable data related to short-term pumping tests. Singer et al.(1999) used these data to determine the transmissivity distribution for the sample has been identified. The sample's minimum and maximum transmissivity values were estimated to range from 0.3 to 34,800 m^2/day, respectively, and the sample's geometric mean was estimated to be about 75 m^2/day.

A sample of 154 wells completed in glaciolacustrine clays have suitable data related to short-term pumping tests. Singer et al.(1999) used these data to determine the transmissivity distribution for the sample. The minimum and maximum transmissivity values were estimated to range from 0.14 to 1,262 m^2/day, respectively, and the geometric mean was estimated to be about 67m^2/day.

Singer et al.(1999) concluded, based on the analyses of the transmissivity distributions for wells completed in various overburden deposits, that wells completed in areas where glaciofluvial ice-contact and outwash deposits outcrop at the surface have the highest water-yielding capabilities. Wells completed in areas where till or glaciolacustrine clays are at the surface are in general less productive. Having said that, it is possible to have highly productive wells completed where till or glaciolacustrine deposits occur at the surface. This is due to the fact that the overburden profile is highly variable both vertically and horizontally, and any overburden well may encounter sand or gravel deposits at some depth.

8.9 SUGGESTED BEDROCK MONITORING AREAS

Figure Se-13 shows the locations of bedrock wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for monitoring groundwater in the bedrock. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials above the bedrock (Figure Se-14).

Areas where groundwater in the bedrock is highly susceptible to contamination are defined as those where the bedrock is either near or at the surface or is covered by highly permeable sand and/or gravel deposits. Areas where the bedrock is moderately susceptible to contamination are defined as those where the overburden above the bedrock contains clay or clay till deposits that are less than 3 m in thickness. Areas where the bedrock has low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, four areas (A, B, C, and D) are proposed for groundwater monitoring within the bedrock. Groundwater susceptibility to contamination within areas (A and B) is high. Area (A) extends along the northeastern topographic divide from Matchedash Bay to Maple Valley and it is underlain mainly by Precambrian rocks. Area (B) extends from Matchedash Bay to the Town of Midland and is underlain by the rocks of the Gull River and Shadow Lake Formations.

Areas (C and D) are underlain by the rocks of the Bobcaygeon Formation and the susceptibility of groundwater to contamination within these two areas is variable. Area (C) extends from the eastern topographic divide to the Village of Coldwater and occupies mainly the middle parts of the North River watersheds. Area (D), on the other hand, extends from the western topographic divide through the northern parts of the Wye River and the Hog Creek watersheds.

8.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Se-15 shows the location of overburden wells with specific capacities of over 50 l/min/m, and the boundaries of suggested areas for groundwater monitoring. Groundwater within the suggested areas has a high, low or variable susceptibility to contamination. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials (Figure Se-16).

Areas where the shallow overburden aquifers are highly susceptible to contamination are defined as those where sand and/or gravel deposits are either near or at the surface. Areas where shallow overburden aquifers are moderately susceptible to contamination are defined as those where the sand and/or gravel deposits are covered by clay or clay till deposits that are less than 3 m in thickness. Areas where the overburden aquifers have low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, six areas (E, F, G, H, I, J, and K) are proposed for groundwater monitoring in the overburden. In addition, groundwater monitoring in Area (K) is optional. Groundwater susceptibility to contamination within areas (E, F, and J) is mainly high, within areas (G, H, and I) is variable, and within area (K) is low.

Area (E) is located between the eastern topographic divide and Bass Lake and it is underlain mostly by till and glaciolacustrine sand and gravel. Area (F) is within the Bass Lake Kame Moraine and is underlain mainly by glaciofluvial sand and gravel. Area (G) is located between Hillsdale and the southern topographic divide and is underlain by till. Area (H) forms the topographic divide between the Coldwater and Sturgeon Rivers and is underlain by till. Area (I) is underlain by till and it forms the upper parts of the Hog Creek watershed. Area (J) extends along the western topographic divide and is underlain mainly by glaciofluvial and glaciolacustrine sand and gravel deposits. Area (K) is located in the Elmvale area within the upper parts of the Wye River and is underlain by clay deposits.

8.11 HISTORICAL MONITORING WELLS

Three historical monitoring wells, which tap groundwater in the overburden, have been identified in the basin. The locations of these wells are as follows:

Well No. 118	The well is 33.53 m deep and located in Simcoe County, Town of Midland.
Well No. 144	The well is 3.66 m deep and located in Simcoe County, Orillia Township, Concession 6, Lot 19.
Well No. 146	The well is 5.49 m deep and located in Simcoe County, Tay township, Concession 8, Lot 9.

Figure Se-17 shows the locations of the historical monitoring wells and Appendix I gives the geographic coordinates of these wells.

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FIGURES

Key Map - Se	A transparency to be used with other figures for orientation purposes.
Figure Se - 1	Bedrock topography in the Severn Sound drainage area.
Figure Se - 2	Bedrock geology in the Severn Sound drainage area.

Figure Se - 3 Overburden thickness in the Severn Sound drainage area.

Figure Se - 4 Overburden geology in the Severn Sound drainage area.

Figure Se - 5 Bedrock wells with specific capacities equal to or less than 5 l/min/m.

Figure Se - 6 Bedrock wells with specific capacities between 5 and 25 l/min/m.

Figure Se - 7 Bedrock wells with specific capacities between 25 and 50 l/min/m.

Figure Se - 8 Bedrock wells with specific capacities higher than 50 l/min/m.

Figure Se - 9 Overburden wells with specific capacities equal to or less than 5 l/min/m.

Figure Se -10 Overburden wells with specific capacities between 5 and 25 l/min/m.

Figure Se -11 Overburden wells with specific capacities between 25 and 50 l/min/m.

Figure Se -12 Overburden wells with specific capacities higher than 50 l/min/m.

Figure Se -13 Suggested areas for monitoring groundwater in the bedrock.

Figure Se -14 Panel diagram showing the geologic logs of bedrock wells with specific capacities higher than 50 l/min/m.

Figure Se -15 Suggested areas for monitoring groundwater in the overburden.

Figure Se -16 Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 50 l/min/m.

Figure Se - 17 Locations of historical monitoring wells in the Severn Sound drainage area.

CHAPTER 9

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE SOUTH NATION RIVER DRAINAGE BASIN

By

S.N. Singer, S. Emami, A. Price, and C. K. Cheng

9.1 LOCATION

The South Nation River drainage basin is located to the east-southeast of Ottawa between longitudes 74^0 41' and 75 ^{0} 44' W and latitudes 44 ^{0} 38' and 45 ^{0} 34' N. The basin covers an area of about 3915 km^2, which includes a small area of about 215 km ^{2} drained by a number of small tributaries to the Ottawa River. From its source, a few kilometers north of Brockville, to its confluence with the Ottawa River, the South Nation River traces a course of 177 km and descends about 84 m. Major sub-basins are the Castor River (733 km^2), the Bear Brook (487 km^2), and the Scotch River (272 km^2).

The South Nation River drains an almost flat plain. Surface elevations range between 45 m above mean sea level in the north and 122 m in the south. Land drainage in many parts of the basin is poor and many ditches have been constructed to improve drainage. Numerous swamps and bogs occur in topographically low areas, the largest ones being Alfred, Mer Bleue, Winchester and Moose Creek bogs.

Large sections of the South Nation River are characterized by small channel capacities and low gradients which are responsible for flooding. Spring floods which are virtually an annual occurrence and occasional summer floods occur mainly above Chesterville and above Plantagenet.

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

9.2 LAND USE

Approximately 60% of the land base within the South Nation River basin is devoted to agriculture. The main agricultural products are corn, grain, and hay. Specialty agriculture includes market gardens, nurseries, orchards, and sod farms. Woodlands cover about 23% of the basin, idle lands about 9%, and urban areas, forest plantations, and wetlands cover the remaining 8%.The main urban centres in the basin are Casselman, Chesterville, Plantagenet, and Winchester.

9.3 GROUNDWATER USE

There are 10,562 records on file with the Ministry of the Environment for water wells constructed in the South Nation River basin. Of these, 8,811 (83.42%) are bedrock wells, 1,138 (10.77%) are overburden wells, and the remaining 613 (5.81%) are of unknown type.

Although groundwater in the basin is available in adequate quantities for private domestic supplies and municipal supply for many small communities, it is not readily available to meet the needs of large municipalities or industries. Of the aquifers identified in the basin, only the Rideau Front Aquifer along the western boundary of the basin appears to have the potential for large-capacity municipal and industrial wells.

Because groundwater is used by thousands of home owners and by many small communities in the basin, it represents an important asset. As communities grow, surface waters will have to play an increasingly important role in augmenting the available groundwater supplies.

The most common groundwater concerns in the basin relate to inadequate supply and poor quality. Wells with inadequate supplies are located predominantly in the clay plain areas in the central and northern parts of the basin where there are no dependable overburden aquifers and where groundwater in bedrock is highly mineralized. Groundwater quality problems consist of salty, highly mineralized, and sulphurous waters. Salty and highly mineralized waters are derived predominantly from bedrock wells in the northern part of the basin, notably in the Bear Brook Valley and the South Nation Valley. Sulphurous waters occur mainly in bedrock wells in the central parts of the basin.

9.4 PHYSIOGRAPHY

According to Chapman and Putnam (1984), parts of five physiographic regions are found within the South Nation River basin. These are the Edwardsburg Sand Plain, the Glengarry Till Plain, the Winchester Clay Plain, the Russell and Prescott Sand Plains, and the Ottawa Valley Clay Plains.

The Edwardsburg Sand Plain physiographic region lies almost completely within the southwestern parts of the basin. The topography of the sand plain is mostly level or gently undulating, although hummocks and ridges appear in places. According to Chapman and Putnam (1984), the sand was deposited by the melting glacier in the form of kames and subsequently spread about by the waves of the Champlain Sea. The main urban centres within this region are Maynard, Domville, and Spencerville.

The Glengarry Till Plain physiographic region is located in the southeastern portion of the basin and it is a part of a larger region of low relief forming the drainage divide between the international section of the St. Lawrence and the Ottawa basin. The surface of the plain is undulating to rolling, consisting of long morainic ridges and a few well-formed drumlins together with intervening clay flats and swamps (Chapman and Putnam 1984). A number of tributaries to the South Nation River arise within this physiographic region, including the South Branch, the Black Creek, Payne River, and Scotch River. The main urban centres are Avonmore, Finch, Newington, and Williamsburg.

The Winchester Clay Plain lies between the Glengarry Till Plain and the sand plains of United Counties of Prescott and Russell. It is an area of low relief, lying almost entirely within the drainage basin of the South Nation River. In many places within the clay plain, the underlying till protrudes and there are a few low drumlins. The soils are imperfectly drained and municipal ditches have been cut to provide drainage throughout the clay plain, and very little uncleared land remains. The main urban centres include Winchester, Chesterville, Casselman, and Maxville (Chapman and Putnam 1984).

The Russell and Prescott Sand Plains physiographic region is located in the United Counties of Prescott and Russell, and the Regional Municipality of Carleton-Ottawa. The region consists of a belt of large sand plains separated by the clays of the lower Ottawa valley. Most of the plains are within the drainage basin of the South Nation River, but smaller parts drain to the Rideau and Ottawa Rivers. The South Nation River cuts a canyon 22 m deep across the plains from Casselman to Lemieux.

The Russell and Prescott Sand Plains have a level surface whose elevation is approximately 75 m above sea-level, while the bottoms of the intervening clay-floored valleys lie below 60 m. According to Chapman and Putnam (1984), the plains, excepting the higher sands south of Ottawa, were at first a continuous delta built by the Ottawa River into the Champlain Sea. The delta was cut to pieces later by the Ottawa River when it rose above sea level.

The Ottawa Valley Clay Plains physiographic region extends between Pembroke and Hawkesbury and occurs within the basin in Plantagenet, Clarence, and Cumberland Townships where the valley is occupied by the South Nation River and its tributary the Bear Brook. The region consists of clay plains interrupted by ridges of rock or sand. Drainage is generally poor and the Nation River above Plantagenet periodically overflows its banks, flooding the adjacent flats and depositing a little alluvium in the process.

9.5 BEDROCK TOPOGRAPHY AND GEOLOGY

The bedrock elevation within the South Nation River basin ranges from 40 and 120 m , but most of the basin is between 40 and 80 m (Figure So-1). Areas with higher bedrock elevations are located along the eastern, southern, and western boundaries. The largest bedrock valley extends northeastward from the Russell-Embrun area and coincides roughly with the present valley of the South Nation River. The channel of the valley is about 10 km wide and 15 m deep. The valley is joined by smaller bedrock valleys that coincide with valleys of Castor, the Bear Brook and Scotch Rivers. Faulting is extensive throughout the bedrock. In many cases the faults serve as geologic boundaries.

A very small area near the northwestern boundaries of the basin in Gloucester Township has been identified as part of the Nepean Formation of Upper Cambrian age. The formation consists of sandstones with conglomerate interbeds, and has thickness of up to 300 m (Thurston et al.1992) . Due to its limited areal extent, the Nepean Formation is of no hydrogeologic significance in the basin.

Much of the southwestern parts of the basin is underlain by rocks of the March and Oxford Formations of Lower Ordovician age. The March Formation consists of sandstones, dolomitic sandstones, sandy dolostones and dolostones. It ranges in thickness from 6 to 64 m. The Oxford Formation consists of dolostones with a maximum thickness of 200 m.

The Rockcliffe Formation of Middle Ordovician age occurs in a number of small areas in the central and northern parts of the basin. It consists mainly of sandstones and shales and has a thickness up to 125 m (Thurston et al.1992).

Rocks of the Gull River, Bobcaygeon, Verulam and Lindsay Formations occur over large areas in the eastern and northern parts of the basin. Along with the Shadow Lake Formation, these units comprise the Ottawa Group in eastern Ontario.

The Gull River Formation, with a thickness range of 7.5 to 136 m, is divided into a lower member and an upper member. The lower member consists of limestones and silty dolostones, whereas the upper member consists of limestones. The Bobcaygeon Formation consists of 7 to 87 m of limestones with some shales. The Verulam Formation consists of limestones with interbeds of shales and has a thickness range of 32 to 65 m. The youngest unit in the sequence is the Lindsay Formation. It has a thickness of up to 67 m and consists of limestones and calcareous shales (Thurston et al. 1992).

The Upper Ordovician strata within the upper part of the basin is represented by the Billings, Carlsbad and Queenston Formations. The Billings Formation consists of shales and has a thickness of up to 62 m. The Carlsbad Formation, with a maximum thickness of 186 m, is comprised of interbedded shales, siltstones and limestones. The youngest unit in the Upper Ordovician sequence is the Queenston Formation which consists of shales with interbeds of limestones and calcareous siltstones (Thurston et al. 1992).

Figure So-2 is a simplified bedrock map geologic of the basin. The rocks of Nepean, March and Oxford Formations are shown as one unit. Similarly the rocks of the Billings, Carlsbad and Queenston Formations are shown as a single unit. Further, the Gull River, Bobcaygeon, and Lindsay Formations are combined under the Ottawa Group. Such grouping of formations, which is based largely on lithology, is extremely useful from a hydrogeologic point of view.

9.6 OVERBURDEN THICKNESS AND GEOLOGY

The overburden deposits within the South Nation River basin consist of glacial, glaciomarine, marine, and fluvial deposits of Pleistocene age with minor amounts of alluvial and swamp deposits of Recent age. The bedrock outcrops at the surface at several locations within the basin, namely, in the southernmost parts of the basin, along the western topographic divide near South Gloucester and Metcalfe, and in the northwestern parts of the basin. Elsewhere, the overburden thickness ranges from less than10 m over most of the southern areas to more than 50 m in the northeastern and central areas (Figure So-3). Within most of the Prescott and Russell Sand Plains, the thickness of the overburden is generally greater than 30 m, however, the thickness of sand deposits themselves are usually less than 6 m.

Glacial deposits occur as undrumlinized and drumlinized till plains. The undrumlinized till plain occurs mostly along the eastern boundaries of the basin, whereas the drumlinized plain occurs mainly within Edwardsburg Sand Plain and the Winchester Clay Plain physiographic regions where the till protrudes as low drumlins. The Champlain Sea, which inundated the area following the last glaciation, has removed or modified the till within the Winchester Clay Plain physiographic region through erosion. Barnett et al.(1991) mapped the undifferentiated till within the South Nation River basin as Map Unit 19 on Map 2556 of the Quaternary Geology of Ontario. According to Barnett (1992), the till of Map Unit 19 was deposited during the Two Creeks Interstade as a result of minor oscillations of the ice margin. It is predominantly a stoney, sandy silt to silt till with a loamy texture.

Fine-grained marine sediments of silt and clay cover most of the Winchester Clay Plain and the Ottawa Valley Clay Plains. These sediments were deposited in deep water. Coarse-grained marine and deltaic sediments form the Edwardsburg Sand Plain and Russell and Prescott Sand Plains. By and large, these sediments were deposited under shallow water conditions. In addition, a small esker-like, ice-contact deposits extend to the north and south of Sarsfield.

Marine beach and bar deposits are found to the south of Maxwell along the eastern topographic divide and to the south of Greely along the western topographic divide. Extensive swamp deposits consisting of peat and muck are found in topographically low areas mainly within Alfred, Mer Bleue, Winchester, and Moose Creek bogs (Figure So-4).

9.7 GROUNDWATER OCCURRENCE IN THE BEDROCK

As indicated earlier, most of the wells in the South Nation River basin are bedrock wells.

Chin et al.(1990) indicated that the groundwater supplies from bedrock aquifers in the basin provide adequate quantities of water for domestic uses but are generally inadequate for uses requiring higher yields. Based on lithologic composition, Chin et al.(1980) identified three major bedrock aquifers in the basin, a limestone/shale aquifer, a limestone/dolomite aquifer, and a sandstone aquifer. Together, the limestone/shale and limestone/dolomite aquifers cover about four-fifth the basin.

From a geologic point of view, the sandstone aquifer, identified by Chin et al.(1980), is most likely the March formation, the limestone /dolomite aquifer is the Oxford Formation, and the limestone/shale aquifer consists of formations which are members of the Ottawa Group. According to Chin et al.(1980), the sandstone aquifer, which has a limited extent, is the most productive bedrock aquifer in the basin. The limestone/dolomite aquifer has the potential for higher yields and it usually contains fresh water. The limestone/shale aquifer, on the other hand, often contains saline and highly mineralized waters.

Based on lithologic considerations, Singer et al.(1997) treated Nepean, March, and Oxford Formations in eastern Ontario as one hydrogeologic unit. For the same reasons, they treated all the formations within the Ottawa Group as well as the Billings, Carlsbad and Queenston Formations as single hydrogeologic units.

Singer et al.(1997) calculated the transmissivity values for a sample of 7,418 wells constructed within the Nepean-March-Oxford hydrogeologic unit in eastern Ontario. The geometric mean of the sample's transmissivity values was estimated to be about 20 m^2/day and the water-yielding capability of the hydrogeologic unit was assessed as being good.

The transmissivity values for a sample of 1,771 wells constructed in the Rockcliffe Formation in eastern Ontario were also calculated by Singer et al.(1997). The minimum and maximum transmissivity values for the sample were estimated to range between 0.10 and 2,906 m^2/day, respectively, the geometric mean of the sample's transmissivity values was estimated to be 15.52 m^2/day, and the water-yielding capability of the Rockcliffe Formation was described as being good.

Singer et al.(1997) calculated the transmissivity values for a sample of 7,251 wells constructed within the Ottawa Group in eastern Ontario. The minimum and maximum transmissivity values for the sample were estimated to range between 0.05 and 8,080 m^2/day, respectively. The geometric mean of the sample's transmissivity values was estimated to be about 12 m^2/day, and the water-yielding capability of the Ottawa Group was assessed as being good.

A sample of 969 wells, constructed in the Billings-Carlsbad-Queenston hydrogeologic unit in eastern Ontario, was selected by Singer et al. (1997) to evaluate the transmissivity distribution for the unit. The minimum and maximum transmissivity values for the sample were estimated to range between 0.06 and 1,803 m^2/day. The geometric mean of the sample's transmissivity values was estimated to be about 6 m^2/day and the water-yielding capability of the unit was assessed as being fair.

Short-term pumping tests are available for 8,117 bedrock wells within the basin. Of these, 2,445 wells (30.12 %) have specific capacities less than 5 l/min/m (Figure So-5), 3,590 wells (44.22 %) have specific capacities between 5 and 25 l/min/l (Figure So-6), 910 wells (11.22 %) have specific capacities between 25 and 50 l/min/m (Figure So-7), and 1,172 wells (14.44 %) have specific capacities higher than 50 l/min/m (Figure So-8).

Based on the spatial distribution of high capacity bedrock wells on Figure So-8, it is possible to conclude that the majority of these wells are located within the March, Oxford, and Rockcliffe Formations and the Ottawa Group. Fewer high capacity wells are found within the Billings, Carlsbad, and Queenston Formations. The spatial distribution of the high capacity wells on Figure So-8 is consistent with the findings of Singer et al.(1997). It is also consistent with the general description of groundwater occurrence in the bedrock by Chin et al.(1980).

9.8 GROUNDWATER OCCURRENCE IN THE OVERBURDEN

Compared to the bedrock, the overburden is not a significant source of groundwater within the South Nation River basin. Overburden aquifers are generally the main sources of ground water in the north. In the southern parts of the basin, the overburden deposits are generally thin (less than 15 m) and are predominantly clays, silts, and tills. Permeable sands occur as surficial deposits over large areas in the north. Also, highly permeable surficial sand and gravel deposits occur along the western boundary of the basin. The latter are generally over 15 m thick. Elsewhere, sands and gravels occur as thin lenticular and discontinuous layers in buried deposits and are generally less than 3 m thick.

Chin et al.(1980) identified a number of overburden aquifers in the basin. The largest overburden aquifer, the Champlain Aquifer, is composed of surficial sands. The aquifer covers an area of nearly 570 km^2. The boundaries of this aquifer as outlined by Chin et al.(1980) correspond to the boundaries of the Prescott and Russell sand Plains.

The most important overburden aquifer is the Rideau Front Aquifer, which is composed of surficial sands and gravels. Compared to the Champlain Aquifer, this aquifer is of smaller extent (105 km^2) but is significant because of its potential for high well yields.

Chin et al.(1980) also identified nine smaller aquifers composed of buried sand and gravel. These aquifers are the Rockland, Plantagenet, Sarsfield, Notre Dame, Clarence, Bourget, St. Rose de Prescott, Maple Ridge, and Berwick aquifers. These aquifers occupy a total area of about 60 km^2.

Data related to short-term pumping tests are available for 1,102 overburden wells. The data indicate that 213 wells (49%) have specific capacities ranging from 1 to 5 l/min/m

(Figure So-9), 557 wells (39.5%) have specific capacities between 5 and 25 l/min/m (Figure So-10), 131 wells (5.9%) have specific capacities between 25 and 50 l/min/m (Figure So-11), and the remaining 201 wells (5.6%) have specific capacities larger than 50 l/min/m (Figure So-12).

Figure So-12 indicates that there are no high-capacity wells within the Champlain Aquifer. Most of the high-capacity wells are found along a belt extending to the south of the Champlain Aquifer from St. Isidore de Prescott in the east to the western boundaries of the basin. This belt includes the St. Isidore de Prescott and the Rideau Front Aquifers, which were identified by Chin et al.(1980). High-capacity wells are also found in the northwestern part of the basin near Sarsfield, Rockland, and Clarence which correspond to the Sarsfield, Rockland, and Clarence Aquifers identified by Chen et al.(1980).

9.9 SUGGESTED BEDROCK MONITORING AREAS

Figure So-13 shows the locations of bedrock wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for monitoring of groundwater in the bedrock. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials above the bedrock (Figure So-14, Panel Diagram).

Areas where groundwater in the bedrock is highly susceptible to contamination are defined as those areas where the bedrock is either near or at the surface or is covered by highly permeable sand and/or gravel deposits. Areas where the bedrock is moderately susceptible to contamination are those areas where the overburden above the bedrock contains clay or clay till deposits that are less than 3 m in thickness. Areas where the bedrock has low susceptibility to contamination are those where the overburden contains clay or clay till deposits that are much more than 3 m in thickness.

Based on the above definitions, eight areas (A, B, C, D, E, F, G and H) are proposed for groundwater monitoring within the bedrock. Areas (A, B, and C) are underlain by the March and Oxford Formations, Area (D) is underlain by the Rockcliffe Formation, areas (E, F, and G) are underlain by the rocks of the Ottawa Group, and Area (H) is underlain by the Billings, Carlsbad and Queenston Formations.

Groundwater susceptibility to contamination within areas (A and B) is high. Area (A) is located at the lower end of the basin and the bedrock in this area is at or close to the surface. Area (B), on the other hand, extends along the basin's western boundary from Kempark to Mountain and includes the headwaters of the North, Middle, and South Rivers and the Allen, Silver, and Wylie Creeks. The bedrock within Area (B) is either at the surface or it is covered by permeable deposits of sand and gravel.

Groundwater susceptibility to contamination within Areas (C, D, E, and H) is moderate.

Area (C) covers parts of Edwardsburgh, Oxford, and South Gower Townships; Area (D) is located between Winchester in the northeast, Winchester Bog in the northwest, and Inkermar in the south; Area (E) is located within Osnabruck and Finch Townships extending from the southeastern basin's boundaries to Crysler; and Area (H) is located within the headwaters of Bear Brook extending from Vars in the southeast to Navah in the northwest.

Groundwater susceptibility to contamination within areas (F and G) is low. Area (F) is located within South Plantagenet and Kenyon Townships in the headwater areas of the East Branch Scotch River and the west Branch Scotch River, and Area (G) is located within Clarence Township between Bourget in the south, St. Pascnal in the east, and the Clarence Creek in the northwest.

9.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure So-15 shows the location of overburden wells with specific capacities of over 50 l/min/m, and the boundaries of suggested areas for groundwater monitoring. Groundwater within the suggested areas has a high, variable, or low susceptibility to contamination. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials (Figure So-16, Panel Diagram).

Areas where groundwater in the overburden is highly susceptible to contamination are defined as those areas where the overburden aquifer is at the surface and consists of sand and gravel materials. Areas where the susceptibility of the groundwater is variable are those areas where the overburden aquifer of sand and gravel is at the surface or is covered by thin clay or clay till deposits. Areas where the susceptibility of groundwater to contamination is low are those where the overburden aquifer is protected by thick clay till or clay deposits.

Based on the above definitions, six areas (A, B, C, D, E, and F) are proposed for groundwater monitoring in the overburden. Area (A) is located along the basin's western topographic divide within the headwaters of the North, Middle , and South Castor Rivers.

The susceptibility of groundwater to contamination within areas (B and C) varies from high to low. Area (B) is located within Winchester and Russell Townships to the northwest of Morewood; and Area (C) is located within Cumberland Township arround Sarsfield.

The susceptibility of groundwater to contamination in areas (D, E, and F) is low. Area (D) is occupies parts of Finch, Cambridge, and Russell Townships extending from Crysler in the south to Embrun in the west. Area (E) is located within Plantagenet and Cambridge Townships extending from St.Isidore de Prescott in the east to Casselman in the west. Finally, area (F) is located in the vicinity of Cumberland in Cumberland Township.

9.11 HISTORICAL MONITORING WELLS

Six bedrock wells, two overburden wells, and three wells of unknown type were used in the past for monitoring groundwater in the South Nation River basin. The types and locations of these wells are as follows:

Well No. 152	A bedrock well, 15.54 m deep, and located in Dundas County, Chesterville Village.
Well No. 257	An overburden well,10.67 m deep, and located in Prescott County, Plantagenet Village.
Well No. 517	A bedrock well, 50.29 m deep, and located in Dundas County, Matilda Township, Concession 4, Lot 13.
Well No. 518	A bedrock well, 38.10 m deep, and located in Grenville county, Augusta Township, Concession 4, Lot 14.
Well No. 519	A bedrock well, 31.39 m deep, and located in Glengarry County, Kenyon Township, Concession 21, Lot 6.
Well No. 520	A well of unknown type, 1.83 m deep, and located in Stormont County, Finch Township, concession 6, Lot 23.
Well No. 522	A well of unknown type, 4.88 m deep, and located in Dundas County, Chesterville Village.
Well No. 523	A well of unknown type, 9.45 m deep, and located in Grenville County, Edwardsburgh Township, Concession 7, Lot 32.
Well No. 525	An overburden well, 14.33 m deep, and located in Russell County, Russell Township, Concession 9, Lot 3.
Well No. 546	A bedrock well, 44.81 m deep, and located in Russell County, Clarence Township, Concession 6, Lot 18.
Well No. 547	A bedrock well, 42.98 m deep, and located in Dundas County, Winchester Township, Concession 6, Lot 1.
Well No. 555	A bedrock well, 21.33 m deep, and located in Ottawa-Carlton County, Gloucester Township, Concession 5, Lot 28.

Figure So-17 shows the locations of the historical monitoring wells and Appendix I gives the geographic coordinates of these wells.

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FIGURES

Key Map - So	A transparency to be used with other figures for orientation purposes.
Figure So - 1	Bedrock topography in the South Nation River drainage basin.
Figure So - 2	Bedrock geology in the South Nation River drainage basin.
Figure So - 3	Overburden thickness in the South Nation River drainage basin.
Figure So - 4	Overburden geology in the South Nation River drainage basin.
Figure So - 5	Bedrock wells with specific capacities equal to or less than 5 l/min/m.
Figure So - 6	Bedrock wells with specific capacities between 5 and 25 l/min/m.
Figure So - 7	Bedrock wells with specific capacities between 25 and 50 l/min/m.
Figure So - 8	Bedrock wells with specific capacities higher than 50 l/min/m.
Figure So - 9	Overburden wells with specific capacities equal to or less than 5 l/min/m.
Figure So -10	Overburden wells with specific capacities between 5 and 25 l/min/m.
Figure So -11	Overburden wells with specific capacities between 25 and 50 l/min/m.
Figure So -12	Overburden wells with specific capacities higher than 50 l/min/m.
Figure So -13	Suggested areas for monitoring groundwater in the bedrock.
Figure So -14	Panel diagram showing the geologic logs of bedrock wells with specific capacities higher than 50 l/min/m.
Figure So -15	Suggested areas for monitoring groundwater in the overburden.

Figure So -16	Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 50 l/min/m.
Figure So - 17	Locations of historical monitoring wells in the South Nation River drainage basin.

CHAPTER TEN

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE THAMES RIVER DRAINAGE BASIN

By

S.N. Singer, A. McDonald, and C.K. Chentg

10.1 LOCATION

The Thames River drainage basin is located in southern Ontario between longitudes 80^0 30' and $82^045'$ W and latitudes $42^000'$ N and $43^030'$ N. The basin has a total area of approximately 5700 km^2, extending from the river's headwaters in Oxford and Perth Counties to its mouth at Lake St. Clair near Tilbury. The basin is 200 km long with a maximum width of about 56 km. The topography of the basin is relatively flat as the river drops roughly 170 meters over its length, an average of 0.85 meter per kilometer.

The upper Thames basin is almost round in shape with a drainage area of about 3575 km^2 and it includes several streams. The North Thames River drains about 1710 km^2 in the northwest section of the basin, its major tributaries include the Avon and Medway Rivers. The main branch of the Thames River above London drains about 905 km^2 in the northeast part of the basin. The Middle Thames River and the Waubuno, Reynolds, and Cedar Creeks are its main tributaries.

The lower Thames River basin is about 2250 km^2 and extends from Delaware to Lake St. Clair. The basin is roughly rectangular in shape, with a length of about 137 km and a maximum width of about 22 km. There are numerous short tributaries to the Lower Thames. Those tributaries entering the main stream from the north are generally less than 15 km long, while those from the south are generally longer and drain larger areas. The largest of the latter are the Jeanette, McGregor, and Big Creeks.

The basin includes parts of Elgin, Essex, Huron, Kent, Lambton, Middlesex, Oxford, and Perth Counties.

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

10.2 LAND USE

The Thames River basin contains agricultural lands, pastures, idle lands, forests, pits and quarries, and urban areas. The component of the basin's economy is agriculture. Agricultural activities, which are diversified from area to area depending on soil and climatic conditions, include livestock raising, dairying, production of corn, soybeans, mixed grains, oats, tobacco, wheat, and hay.

Dairying is the mainstay of the many farms in Oxford and eastern Middlesex Counties and tobacco in south-central Middlesex County. Mixed farming is widespread in Perth and Middlesex Counties. Corn, soybeans, wheat, and cannery crops such as tomatoes and peaches are grown in Kent and eastern Essex Counties.

The agricultural base of the Thames River basin is complemented by industry and commerce in several urban centres. The main urban centres in the basin are London, Woodstock, Chatham, and Stratford.

10.3 GROUNDWATER USE

Ground water in the Thames River basin is a valuable and critical resource. This important agricultural area depends to a large extent on wells for its farm, domestic, commercial, industrial and municipal water supplies.

The total number of water wells within the Thames River basin that have geographic coordinates on file with the Ministry of the Environment is 18,121. Of these wells, 8,563 (47.2%) are overburden wells, 8,149 (44.9%) are bedrock wells, and the rest are of unknown type. Most of the wells in the upper Thames basin are drilled to rock and most wells end in limestone, whereas toward the south an increasing number of wells obtain water from shallow and intermediate aquifers in the overburden. Nevertheless, both overburden and bedrock wells are common in most areas in the basin, reflecting generally an even utilization of overburden and bedrock aquifers.

Most wells are used to provide rural domestic supplies and the highest density of wells occurs around the City of London, which obtains its own water by pipeline from Lake Huron. The City, however, maintains several former municipal wells for standby purposes. The largest municipalities within the basin using groundwater are Woodstock, Stratford, Ingersoll, St. Mary's, and Mitchell.

Hardness, iron and total dissolved solids are the most common groundwater quality problems. In most cases these problems are not severe and are accepted by the consumers, often simple treatment by softening is the solution. Local problems related to high chloride or hydrogen sulphide concentrations occur with supplies from bedrock and these are more troublesome and less easily dealt with (Goff and Brown 1981).

Apart from the lack of suitable supplies of groundwater for industrial and municipal uses in some areas, the major groundwater concerns in the Thames River basin relate to the potential contamination and security of aquifers and individual wells. The major problems are with wells tapping the shallow aquifers on the Bothwell and Caradoc Sand plains. Wells in these areas are very susceptible to surface sources of contamination. Incidents of well contamination were related to malfunctioning private septic systems, agricultural chemical fertilizers, road salting, landfill sites, and hydrocarbon spills.

10.4 PHYSIOGRAPHY

Chapman and Putnam (1984) identified seven physiographic regions within the Thames River basin: the Stratford Till Plain, the Oxford Till Plain, the Mount Elgin Ridges, the Caradoc sand Plains, the Ekfrid Clay Plain, the Bothwell Sand Plain, and the St. Clair Clay Plains.

Most of the central and southern portions of Stratford Till Plain physiographic region is within the Thames basin, extending from Blyth and Listowel in the north to London in the south. The overall slope is towards the southwest, from approximately 450 to 275 m (a.s.l.). The region is covered by ground moraine interrupted by several terminal moraines. The till, throughout the region, is fairly uniform, being calcareous silty clay till whether on the ridges or the more level ground moraine. Stratford, Listowel, and St. Mary's are the main urban centres in this region (Chapman and Putnam 1984).

The Oxford Till Plain physiographic region occurs within the upper part of the Thames basin in Oxford County. The surface, which ranges in elevation from 300 to 365 m, is a drumlinized till plain, with well-formed drumlins appearing south of Woodstock and faint drumlins and flutings farther north. Both the drumlins and flutings have a northwest alignment. A group of kames, around Lakeside in the northwest corner of Oxford County, is also included in this region. The main urban centres in the region are Woodstock and Ingersoll (Chapman and Putnam 1984).

A small area along the southeaster boundaries of the basin is occupied by the Mount Elgin Ridges physiographic region. The region, which extends between the Thames Valley and the sand plain of Norfolk and Elgin Counties, consists of a succession of ridges and vales. The ridges are moraines of calcareous clay or silty clay, while in the vales it is common to find alluvium of gravel, sand, or silt. The Ingersoll Moraine is part of this region and its northern slope drains directly into the Thames. The Reynolds and Dingman Creeks, two small tributaries of Thames River, provide drainage for two sections of the flat-floored trough south of the Ingersoll Moraine (Chapman and Putnam 1984).

The Caradoc Sand Plains physiographic region occurs in the neighborhood of the City of London. It consists of a series of small plains which are covered with sand or other light-textured, water laid deposits. The surface of this physiographic region is nearly level and ranges in elevation between 240 to 260 m (a.s.l.). The sands of Caradoc thin out toward the west until eventually the underlying clay appears on the surface. The main urban centres in the region are London, and Strathroy (Chapman and Putnam 1984).

The Ekfrid Clay Plain physiographic region is located west and south of the Caradoc Sand Plain and consists of stratified clays. The surface is nearly level except where it is cut by gullies near the Thames River. Here and there, knolls or low smooth ridges of sand and gravel are superimposed on the clay. The clay beds are thinnest between the Thames River and St. Thomas where the boulder clay often comes to the surface (Chapman and Putnam 1984).

According to Chapman and Putnam (1984), the Bothwell Sand Plain physiographic region is the delta of the Thames River in glacial Lake Warren and stands at an altitude of between 180 and 215 m (a.s.l.). The sands, which are about 1 m in thickness, were spread thinly over a clay floor. The sand plain is cut in two by the Thames River.

The Lake St. Clair Clay Plains physiographic region is located in the vicinity of Lake St. Clair in Essex and Kent Counties and consists of extensive clay plains. The region is one of little relief, lying mostly between175 and 215 m (a.s.l.). Glacial Lake Whittlesey, which deeply covered all of these lands, and Lake Warren, which subsequently covered nearly the whole area, failed to leave deep stratified beds of sediment on the underlying clay till.

10.5 BEDROCK ELEVATION AND GEOLOGY

Palaeozoic rocks formed in ancient seas underlie the Thames River basin. These rocks were deposited on the sloping surface of the Precambrian rocks and formed successive layers. Subsequent erosion produced the northwest trending rock formations seen on geologic maps of this area.

The bedrock elevation within the basin ranges from about 120 m near the mouth of the river to above 320 m in the northwestern corner of the basin (Figure Th-1). The bedrock elevation within the upper Thames basin ranges from 200 to more 320 m, with a general gradient of about 2 m per km. Within the lower Thames basin, the bedrock elevation ranges from120 to 200, with a gradient of about 0.6 m per km. These differences in gradients between the upper and lower parts of the Thames River basin are reflected in the surface topography of the basin.

The rocks of the Salina Formation of Upper Silurian age are the oldest rocks found at the bedrock surface within the northeastern part of the basin (Figure Th-2). The Salina Formation has been subdivided into 8 units, named A -1, A -2, and B through G. In general, these units consist of dolostones, evaporites, evaporitic carbonates and shales. The total maximum thickness of the Salina Formation is 330 m (Thurston et al. 1992).

The youngest Silurian strata in the basin is represented by the Bass Island Formation which occurs along a roughly northwest trending line through New Durham, Innerkip, and Shakespeare. The formation consists of dolostones and its Its thickness ranges from 22 to 28 metres (Thurston et al.1992).

Overlying the rocks of the Bass Island Formation are the rocks of the Bois Blanc Formation of Lower Ordovician. The formation, which range in thickness from 3 to 50 metres, occurs in a narrow band extending from the Niagara Peninsula to Lake Huron. It consists of cherty limestones that grade into dolostones toward the west (Thurston et al. 1992).

The Middle Devonian sequence within the basin includes the rocks of the Detroit River Group, the Dundee Formation, and the Hamilton Group. The major types of rocks are limestones, dolostones, sandstones and shales.

The rocks of the Detroit River Group within the basin consist of the Amherstburg and Lucas Formations. The Amherstburg Formation consists of 40 to 60 m of limestones which become dolostones toward the southwest; while the Lucas Formation consists of 40 to 75 m of limestones and dolostones with thin anhydrite and/or gypsum partings. Overlying the Lucas Formations, are the rocks of the Dundee Formation which consist of limestones and have an average thickness of 35 to 45 m (Thurston et al.1992).

The rocks of the Hamilton Group, which contains six units: the Bell, Rockport Quarry, Arkona, Hungry Hollow, Widder, and Ipperwash Formations, overlay the Dundee Formation. The lowest unit in the Hamilton Group is the Bell Formation. With an average thickness of 14.5 m, the Bell Formation consists mainly of shales with thin, organic shale interbeds.

The Rockport Quarry Formation consists of limestones with shale interbeds. It has an average thickness of 5.7 m. The Arkona Formation consists of shales with occasional limestone interbeds. It has an average thickness of 32 m. The Hungry Hollow Formation consists of limestones and is about 2 m in thickness. The Widder Formation consists of shales with limestone interbeds. The unit has a maximum thickness of 21 m. The uppermost member of the Hamilton Group is the Ipperwash Formation which consists of limestones with minor chert. The unit's thickness ranges from 2 to 13 m (Thurston et al.1992).

The Kettle Point Formation represents the youngest strata in the Devonian sequence in the basin. The unit has a thickness ranging from 30 to 75 m and consists mainly of shales and siltstones (Thurston et al.1992).

10.6 OVERBURDEN THICKNESS AND GEOLOGY

The overburden within the Thames River basin consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age with minor alluvial and swamp deposits of recent age. The overburden thickness within the basin ranges less than 10 m to over 90 m (Figure Th-3). Small areas with an overburden thickness of less than 10 m are found along the basin's northeastern boundaries. Throughout most of the upper Thames basin, the thickness of the overburden between 10 and 30 m, however, in areas located to the east of Stratford and the southwestern topographic divide, the overburden thickness increases to 70 m and reaches about 90m in small areas. The thickness of the overburden ranges from 10 to 70 m over most of the lower Thames basin, however, it increases to over 90 m to in the vicinity of London and along the southeastern topographic divide.

Six different tills have been identified within the Thames River basin, the Catfish Creek Till, Tavistock Till, Stratford Till, Port Stanley Till, Elma Till, and Rannoch Till. These tills form plains of a ground moraine and a number of end moraines, including Blenheim, Ingersoll, Lucan, Milverton, Mitchell, and Westminister Moraines (Figure Th-4).

The main layer of the Catfish Creek Till is widespread throughout southwestern Ontario in the subsurface, and outcrops in small areas in the vicinity of Woodstock. The till was deposited during the Nissouri Stade. It is a moderately stony to very stony, very compact, highly calcareous, sandy silt to silt till. Matrix carbonate content averages 35 to 60% and is mainly dolomitic (Cowan 1975).

The Tavistock Till was deposited by the Huron-Georgian Bay Lobe during the Port Bruce Stadial. The properties and characteristics of the Tavistock Till change greatly along its outcrop length. It is a highly calcareous, silty clay to clayey silt till of low to medium plasticity within the lower part of the basin. The till occurs as ground moraine, 2 to 15 m thick, commonly interbedded with glaciolacustrine sediments. Farther north in the London and Woodstock area, the Tavistock Till is a strongly calcareous, silt to sandy silt to sand till (Karrow 1974).

The Stratford Till overlies the Tavistock Till and occurs as a thin ground moraine, 1 to 3 m thick, in the vicinity of Stratford. The till was deposited by the Huron-Georgian Bay Lobe. It is a strongly calcareous, sandy silt to silt till with low plasticity.

The Port Stanley Till occurs as ground moraine and within the Ingersoll Moraine along the southeastern boundaries of the basin. The till was deposited by the Ontario-Erie Lobe during the Port Bruce Stadial. It is a strongly calcareous, clayey silt to silty clay till with low plasticity. The thicknesses of the till ranges between 2 and 10 m.

The Elma Till is a deposit of the Georgian Bay Lobe during the latter part of the Port Bruce Stade and probably the following Mackinaw Interstade. The till, which ranges in thickness between 2 and 15 m, occurs as ground moraine in the northwestern parts of the basin in Perth County. It is a strongly calcareous, silty sandy silt and clayey silt till (Karrow 1974).

The Rannoch Till was deposited by the Huron Lobe. It is a strongly calcareous, silty clay till with low plasticity. The till, which is 2 to 6 m thick, occurs as ground moraine along the northwestern boundaries of the basin (Karrow 1977).

Deposits of sand and gravel of glaciofluvial and glaciolacustrine origin are found at the surface as well as at various depths within the overburden. Ice-contact deposits of sand and gravel occur to the west, south and east Thamesford. Glaciofluvial outwash deposits of mainly gravel are found within the Thames River Valley between Woodstock and London. Glaciolacustrine sands are displayed at the surface within the Caradoc Sand Plains and the Bothwell Sand Plain.

Except in the southwestern part of the area near the City of London, buried sand and gravel deposits are not common in the upper Thames River basin. However, such buried deposits at various depths are common within the lower Thames basin.

Glaciolacustrine clay deposits are displayed at the surface within the Ekfrid Clay Plain and the St. Clair clay plains. Recent alluvial deposits are found mainly within the lower part of the Thames River Valley.

10.7 GROUNDWATER OCCURRENCE IN THE BEDROCK

Specific capacity data are available for 5,336 bedrock wells within the Thames River basin. Of these, 1361 wells have specific capacities less than 5 l/min/m (Figure Th-5), 2,374 wells have specific capacities between 5 and 25 l/min/l (Figure Th-6), 727 wells have specific capacities between 25 and 50 l/min/m (Figure Th-7), and 875 wells have specific capacities higher than 50 l/min/m (Figure Th-8). Based on the distribution of wells on Figure Th-8, it is possible to conclude that the rocks of the Bois Blanc Formation, Detroit River Group, and Dundee and Kettle Point Formations are the best bedrock aquifers within the Thames River basin.

The Salina and Bass Island Formations occur within a small area along the eastern topographic boundary of the upper Thames basin. Therefore, only a few wells tap these formations in the basin.

Singer et al.(1997) identified a sample of 2,994 wells with data related to short-term pumping tests within the Salina Formation in southwestern Ontario. The minimum and maximum transmissivity values for the sample were estimated to range between 0.10 and 10,200 m^2/day, respectively. The geometric mean of the sample's transmissivity values was estimated to be 28 m^2/day. Based on these results, Singer et al.(1997) described the Salina Formation as having a very good water-yielding capability.

Singer et al.(1997) identified a sample of 739 wells with data related to short-term pumping tests within the Bass Island Formation in southwestern Ontario. The minimum and maximum transmissivity values for the sample were estimated to range between 0.43 and

14,220m^2/day, respectively. The geometric mean of the sample's transmissivity values was estimated to be about 31m^2/day. The Bass Island Formation was described as having a very good water-yielding capability.

The Bois Blanc Formation occurs over a large area extending as a belt along the eastern parts of the upper Thames basin. Many wells tap this formation within the upper Thames basin and the majority of these wells have specific capacities higher than 50l/min/m.

Singer et al.(1997) identified a sample of 1,069 wells with data related to short-term pumping tests within the Bois Blanc Formation in southwestern Ontario. The minimum and maximum transmissivity values for the sample were estimated to range between 0.41 and 3,905 m^2/day, respectively, and the geometric mean of the sample's transmissivity values was estimated to be about 40 m^2/day. These relatively high value of the sample's geometric mean suggests that the Bois Blanc Formation has an excellent water-yielding capabilities.

A large number of wells tap groundwater within the limestones and dolostones of the Detroit River Group that extends as a wide belt from the northwestern topographic divide of the upper Thames basin to the southwestern divide. Many wells have specific capacities higher than 50l/min/m.

Singer et al.(1997) identified a sample of 6,762 wells with data related to short-term pumping tests within the Detroit River Group in southwestern Ontario. The minimum and maximum transmissivity values for the sample were estimated to range between 0.12 and 6,470 m^2/day, respectively. The geometric mean of the sample's transmissivity values was estimated to be 31 m^2/day. The relatively high value of the sample's geometric mean suggests that the Detroit River Group has a very good water-yielding capability.

A large number of wells tap groundwater within the Dundee Formation which extends over a large area within the upper Thames basin. It is also found within a small area in the vicinity of St. Clair Lake in the lower Thames basin. Many wells have specific capacities higher than 50l/min/m.

Singer et al.(1997) identified a sample of 4,199 wells with short-term pumping tests within the Dundee Formation in southwestern Ontario. The minimum and maximum transmissivity values for the sample were estimated to range between 0.1 and 9,380 m^2/day, respectively. The geometric mean of the sample's transmissivity values was estimated to be 27m^2/day. The water-yielding capability of the Dundee Formation was described as being very good.

Many wells tap groundwater within the Hamilton Group within the lower Thames basin. Most of these wells have specific capacities of less than 5 l/min/m. Singer et al.(1997) identified a sample of 1,044 wells with data related to short-term pumping tests within the Hamilton Group in southwestern Ontario. The minimum and maximum transmissivity values for the sample were estimated to range from 0.11 and 2,638.00 m^2/day, respectively. The geometric mean of the sample's transmissivity values was estimated to be about 5 m^2/day. The relatively low value of the geometric mean of the transmissivity values suggests that the Hamilton Group has only a fair water-yielding capability.

The Kettle Point Formation occurs as a belt within the lower Thames River extending from Chatham-Blenheim in the south to Bothwell-Ridgetown in the north. A large number of wells tap groundwater within this formation and quite a few of these wells have specific capacities over 50 l/min/m.

Singer et al.(1997) identified a sample of 3,096 wells with data related to short-term pumping tests within the Kettle Point Formation in southwestern Ontario. The minimum and maximum transmissivity values for the sample were estimated to range from 0.07 and 1,675 m^2/day, respectively. The geometric mean of the sample's transmissivity values was estimated to be about 9 m^2/day. The water-yielding capability of the Kettle Point Formation was described as being fair.

10.8 GROUNDWATER OCCURRENCE IN THE OVERBURDEN

Most wells tapping the surficial and shallow overburden aquifers supply adequate quantities of good quality groundwater for domestic requirements. Higher water yields are usually limited by the saturated thicknesses of the aquifers. According to Goff and Brown (1981), deep buried sand and gravel aquifers in the overburden are not known to be common in the upper part of the Thames River basin, except in the southwestern part of the area near the City of London. Local deposits have also been mapped south of Ingersoll and in the Stratford and Mitchell areas.

Sand and gravel deposits buried at various depths in the overburden are common, particularly in the central and southwestern portions of the lower Thames River basin. These units typically form excellent aquifers as they yield adequate quantities of good-quality groundwater.

Specific capacity data are available for 4,943 overburden wells within the Thames River basin. Of these, 1,511 wells have specific capacities less than 5 l/min/m (Figure Th-9), 2,090 wells have specific capacities between 5 and 25 l/min/l (Figure Th-10), 593 wells have specific capacities between 25 and 50 l/min/m (Figure Th-11), and 749 wells have specific capacities higher than 50 l/min/m (Figure Th-12).

Most of the high capacity overburden wells are located in the upper Thames basin within an area extending between London, Ingersoll and St. Mary's. Other areas with high capacity wells are located between Stratford and Woodstock, and along the western drainage divide south of Mitchell. Most of the high capacity wells within the Lower Thames River are located within an area extending from south of Chatham in the south to Blenheim in the east, Wardsville in the north, and Thamesville in the west. A second area is located north of Glecoe along the western boundaries of the basin.

10.9 SUGGESTED BEDROCK MONITORING AREAS

Figure Th-13 shows the location of bedrock wells with specific capacities of over 50 l/min/m and the boundaries of areas of low and variable susceptibility to contamination. The susceptibility of bedrock to contamination was based on an examination of the thickness and types of overburden materials above the bedrock (Figure Th-14).

Areas where groundwater in the bedrock is highly susceptible to contamination are defined as those where the bedrock is either near or at the surface or is covered by highly permeable sand and/or gravel deposits. Areas where the bedrock is moderately susceptible to contamination are defined as those where the overburden above the bedrock contains clay or clay till deposits that are less than 3 m in thickness. Areas where the bedrock has low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, four areas (A, B, C, and D) are proposed for groundwater monitoring within the bedrock. Groundwater susceptibility to contamination within areas (A and C) on Figure Th-13 is low and within areas (B and D) is variable.

Area (A) is located in the lower end of the Thames River and is underlain by the Dundee Formation. Area (B) occupies parts of the St. clair Clay Plain and the Bothwell Sand Plain mainly where the Kettle Point Formation underlies the overburden. Area (C) extends along the northwestern topographic divide of the basin where the Lucan moraine occurs. It is underlain mainly by the rocks of the Hamilton Group. Area (D) occupies the northeastern half of the basin and is underlain the Salina, Bass Island, and Bois Blanc Formations, Detroit River Group, Dundee Formation, and Hamilton Group.

Many wells within areas (A, B, and D) are high-capacity wells. An examination of the geologic logs of wells constructed in these areas indicates the presence of sand or gravel deposits at various depths within the overburden.

10.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Th-15 shows the location of overburden wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for groundwater monitoring in the overburden. The susceptibility of groundwater to contamination within the suggested areas was based on an examination of the thickness and types of overburden materials in various wells (Figure Th-16).

Areas where the shallow overburden aquifers are highly susceptible to contamination are defined as those where sand and/or gravel deposits are either near or at the surface. Areas where shallow overburden aquifers are moderately susceptible to contamination are defined as those where the sand and/or gravel deposits are covered by clay or clay till deposits that are less than 3 m in thickness. Areas where the overburden aquifers have low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, four areas (E, F, G, and H) are proposed for groundwater monitoring. Groundwater susceptibility to contamination within most of areas (E and F) is high, while it is mostly low within areas (G and H).

Most of Area (E) is located in lower part of the basin and is covered by the Bothwell Sand Plain or the St. Clair Clay Plain. Many well logs within Area (E) reveal sand and gravel deposits at various depths within the overburden, indicating the presence of upper, middle, and lower aquifers. The upper aquifer within the Bothwell Sand Plain is highly susceptible to contamination.

Area (F) extends from the confluence of Dingman Creek and the Thames River south of London to a line extending from the basin's topographic divide east of Ingersoll to the basin's western divide near the headwaters of the Medway River. Large part of this area is covered with the Caradoc Sand Plain as well as with sand and gravel deposits of glaciofluvial origin. The thickness of these deposits range from 9.7 to 28.3 m near London and from 5.8 to 11.6 m around Ingersoll. Well logs also indicate the presence of sands at depth. Groundwater within the surficial sand and gravel deposits in Area (F) are highly susceptible to contamination. The lower sand and gravel deposits, on the other hand, are protected by clay deposits over 3 m in thickness.

Area (G) is located along the western topographic divide to the southwest of Mitchell. Sand deposits are at the surface in this area mainly within the stream valleys. Many well logs within this area also indicate the presence of clay deposits of over 3 m in thickness.

Area (H) extends along the eastern boundaries of the basin from Stratford to Woodstock. Sand and gravel deposits are found at various depths within the geologic logs of different wells. Clay deposits of over 3 m in thickness are also present.

The Overburden within the remaining areas of the Thames River basin contains thick clay deposits which protect the groundwater from contamination. Monitoring in these areas is optional.

10.11 HISTORICAL MONITORING WELLS

Twenty-one wells and piezometers were used in the past for monitoring groundwater in the Thames River drainage basin. The locations of the wells and piezometers and their historical numbers are as follows:

Well No.13	An overburden well, 22.86 m deep, and located in Oxford County, West oxford township, Concession 3, Lot 2.
Well No. 29	A Bedrock well, 29.57 m deep, and located in Middlesex County, Westminster Township.
Well No. 45	An overburden well, 10.97 m deep, and located in Perth County, Blanshard Township.
Well No. 71	An overburden well, 13.41 m deep, and located in Middlesex County, Westminster Township.
Well No. 95	A bedrock well, 30.78 m deep, and located in Middlesex County, Delaware Township.
Well No. 98	A bedrock well, 33.22 m deep, and located in Middlesex County, Lobo Township, Concession 1, Lot 4.
Well No. 99	An overburden well, 4.57 m deep, and located in Middlesex County, Lobo Township, Concession 3, Lot 3.
Well No. 100	An overburden well, 6.71 m deep, and located in Middlesex County, Lobo Township, Concession 2, Lot 5.
Well No. 103	A bedrock well, 15.85 m deep, and located in Oxford County, East Zorra Township, Concession 12, Lot 4.
Well No. 104	A bedrock well, 6.10 m deep, and located in Oxford County, East Zorra Township, Concession 12, Lot 4.
Well No. 107	A bedrock well, 39.62 m deep, and located in Middlesex County, Lobo Township, Concession 2, Lot 6.
Well No. 108	A bedrock well, 21.34 m deep, and located in Perth County, Downie Township, Concession 14, Lot 1.
Well No. 165	A bedrock well, 25.90 m deep, and located in Oxford County, East Zorra Township, Concession 12, Lot 3. Piezometer No. 166 is within the well at depth of 19.51 m.
Well No. 172	An overburden well, 10.67 m deep, and located in Kent County, Town of bothwell.
Well No. 182	A bedrock well, 134.11 m deep, and located in Perth County, Stratford City.
Well No. 193	A bedrock well, ? m deep, and located in ? County, ? Township, Concession ?, Lot ?
Well No. 206	An overburden well, 6.71 m deep, and located in Middlesex County, Caradoc Township, Concession 1, Lot 15.
Well No. 221	An overburden well, 40.84 m deep, and located in Middlesex County, Mosa Township, Concession 2, Lot 13.
Well No. 309	An overburden well, 7.01 m deep, and located in Kent County,

	Tilbury East Township, Concession 4, Lot 9.
Well No. 345	A bedrock well, 49.07 m deep, and located in Kent County, Harwich Township, Concession 1, Lot 12.
Well No. 371	An overburden well, 21.64 m deep, and located in Kent County, Howard Township, Concession 1, Lot 15.

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FIGURES

Key Map - Th	A transparency to be used with other figures for orientation purposes.
Figure Th - 1	Bedrock topography in the Thames River drainage basin.

Figure Th - 2 Bedrock geology in the Thames River drainagebasin.

Figure Th - 3 Overburden thickness in the Thames River drainage basin.

Figure Th - 4 Overburden geology in the Thames River drainage basin.

Figure Th - 5 Bedrock wells with specific capacities equal to or less than 5 l/min/m.

Figure Th - 6 Bedrock wells with specific capacities between 5 and 25 l/min/m.

Figure Th - 7 Bedrock wells with specific capacities between 25 and 50 l/min/m.

Figure Th - 8 Bedrock wells with specific capacities higher than 50 l/min/m.

Figure Th - 9 Overburden wells with specific capacities equal to or less than 5 l/min/m.

Figure Th -10 Overburden wells with specific capacities between 5 and 25 l/min/m.

Figure Th -11 Overburden wells with specific capacities between 25 and 50 l/min/m.

Figure Th -12 Overburden wells with specific capacities higher than 50 l/min/m.

Figure Th -13 Suggested areas for monitoring groundwater in the bedrock.

Figure Th -14 Panel diagram showing the geologic logs of bedrock wells with specific capacities higher than 50 l/min/m.

Figure Th -15 Suggested areas for monitoring groundwater in the overburden.

Figure Th -16 Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 50 l/min/m.

Figure Th - 17 Locations of historical monitoring wells in the Thames River drainage basin.

CHAPTER 11

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE UPPER NOTTAWASAGA RIVER DRAINAGE BASIN

By

S.N. Singer, A. Price, and C.K.Cheng

11.1 LOCATION

The Upper Nottawasaga River drainage basin is located in south-central Ontario between the longitudes $79^0$35' and $80^0$16' W and the latitudes of $43^0$56' and $44^0$18' N. The basin is approximately 53 km long in an east-west direction and 22 km wide in a north-south direction. It is bounded on the east by the Holland River basin, on the south by the Humber River basin, on the west by the Grand River basin, and on the north by the lower Nottawasaga basin.

The Upper Nottawasaga River and some of its tributaries rise in a plain west of the Niagara Escarpment and flow down the Escarpment through deeply cut rock valleys towards Baxter. From Baxter, the Nottawasaga River flows northward until it discharges into Nottawasaga Bay at Wasaga Beach. The total drainage area of the basin is approximately 1217 km^2. The main sub-basins of the Upper Nottawasaga River are Boyne River (220 km^2), the Sheldon Creek (85 km^2), and the Innisfil Creek (474 km^2). The basin contains portions of the Counties of Dufferin, Peel, Simcoe, and York. There are five main population centres in the basin, Alliston, Beeton, Cookstown, Shelburne, and Tottenham.

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

11.2 LAND USE

Most of the population within the basin is rural and the basin economy is primarily agricultural with emphasis on livestock-raising and mixed farming. The primary uses of land in the basin are for crop production on the sand plain adjacent to the Nottawasaga River, and for improved and unimproved pasture throughout much of the remainder of the basin. A number of special cash crops are cultivated, the most notable being tobacco, potatoes, and sod. Woodland areas occur west of the Niagara Escarpment and within the river valleys.

Alliston is the largest urban center within the basin and has experienced a large rate of population growth since the building of an automobile production facility in the town. Alliston also has a potato processing plant. It also has a plant which produces hospital supplies. Canada Packers Ltd. operates a poultry eviscerating plant in the Village of Shelburne. Honey, tire pumps, and lumber products are also produced in the village.

11.3 GROUNDWATER USE

Groundwater in the Upper Nottawasaga River basin is used for rural domestic water supply, municipal water supply, and livestock watering. Rural water needs are met by groundwater from dug, bored, and drilled wells. Livestock watering, on the other hand, is met from groundwater sources as well as from ponds and streams.

The total number of water wells within the basin that have geographic coordinates on file with the Ministry of the Environment is 4,221. Of these wells, 683 (16.1%) are bedrock wells, 3,338 (79.0%) are bedrock wells, and the rest are of unknown type. The majority of the bedrock wells are located in the western part of the basin.

Municipal water-supply systems exist at Alliston, Beeton, Cookstown, Shelburne, and Tottenham. All of these systems utilize groundwater. Alliston and Beeton obtain their water supplies from wells developed in the Alliston Sand Aquifer, the two municipal wells serving Shelburne are constructed in the Amabel Aquifer, and Cookstown and Tottenham obtain their water supplies from deep overburden wells.

Flowing wells especially those that penetrate the Alliston Sand Aquifer within the Lake Algonquin sand plain are too often left to flow without any particular use being made of the water. This is often a needless waste of the resource and the control of these flowing wells would be an important conservation measure. In addition, groundwater contamination by nutrients and road salts within the extensive areas of sand and gravel east of the Niagara Escarpment and on the Lake Algonquin sand plain is a potential problem that requires continuous attention.

11.4 PHYSIOGRAPHY

According to Chapman and Putnam (1984), the Upper Nottawasaga River basin contains parts of five physiographic regions, the Dundalk Till Plain, the Niagara Escarpment, the Horseshoe Moraines, the Peterborough Drumlin Field, and the Simcoe Lowlands.

A small area in the extreme western part of the basin is part of the Dundalk Till Plain physiographic region which represents the "roof" of peninsular Ontario in the Counties of Dufferin, Grey, and Wellington. The region, which is covered by a fluted till plain, is bounded on the east by moraines. Also, some morainic ridges lie inside the boundary near

Shelburne. The headwaters of the Saugeen, Maitland, Grand Rivers, and the Nottawasaga are located within the Dundalk Till Plain. The plain is characterized by swamps or bogs and by poorly drained depressions.The chief urban center on the plain within the basin is Shelburne.

The Niagara Escarpment is a prominent physiographic feature within the western part of the basin. The Escarpment, which has an elevation of about 485 m (a.s.l.), is exposed locally as vertical cliffs, 35 to 40 m high, for short distances north and south of Mono Center. The cliffs mark the edge of the Silurian dolomite formations. At other localities, the Escarpment is difficult to define and most of the rock slopes are obscured by hummocky, bouldery ridges and deposits of sand and gravel.

The Horseshoe Moraines physiographic region within the basin is a part of a large morainic system that forms a horseshoe shaped region lying around the upland between Lake Huron, Lake Ontario, and Georgian Bay. The region includes several tracts of stony shallow drift on the Niagara cuesta. It also includes an assortment of kame sand and gravel and other ice-contact and meltwater deposits. In the southern portion of this region, the surface material consists mainly of outwash sands and gravels, deposited by glacial meltwater. Generally, the land surface is rugged, in places deeply dissected, and slopes toward the east. Surface elevations range from 240 m in the river valleys to 460 m (a.s.l.) in the area of kame deposits adjacent to the Escarpment.

The Peterborough Drumlin Field physiographic region within the basin is a part of a belt of a rolling till plain with thousands of drumlins that extends from Hastings County in the east to Simcoe County in the west. The physiographic region within the basin covers large areas and contains approximately 100 drumlins which have a northeast-southwest orientation. Land surface elevations range from about 220 m to approximately 420 m (a.s.l.). The main surface deposit in the region is a sand to silt till, but local deposits of clay, sand, and gravel exist in the eastern and southeastern portions of the region.

The Simcoe Lowlands physiographic region includes the plains bordering Georgian Bay and Lake Simcoe. These plains are being drained into Nottawasaga Bay, mostly by way of the Nottawasaga River, and into Lake Simcoe mostly through the Holland River system. The Simcoe Lowlands region consists of flat-lying areas that occur adjacent to the Nottawasaga River. In addition, large portions of the drainage areas of the Boyne River and Sheldon and Innisfil Creeks are part of the region.

Most of the surface elevations within the Simcoe Lowlands region are below 230 m (a.s.l.). The surface deposits consist mainly of fine- to medium-grained sands which were deposited in glacial Lake Algonquin. At lower elevations, very fine sand, silt, and thin clay deposits are present. Above the shoreline of Lake Algonquin, most of the surface deposits are sand and gravel of glaciofluvial origin.

The southernmost portion of the Lowlands, where the Upper Nottawasaga and its tributaries deposited deep beds of sand and silt, is called the Tecumseth Flats. Through these level plains the watercourses have cut only shallow channels and drainage is generally poor. At the head of the Innisfil Creek there is a bog of some 2000 acres, while another of about 1,200 acres is found farther down the creek near Randall Station. A third large bog of about 9,000 acres lies along the Bailey Creek in Tecumseth and Adjala Townships.

11.5 BEDROCK TOPOGRAPHY AND GEOLOGY

The Palaeozoic rocks underlying the Upper Nottawasaga drainage basin consist of shale, dolomite, and limestone of Ordovician and Silurian age. Sibul and Choo-Ying (1971) prepared a map of the bedrock elevation within the basin and described the bedrock topography. A modified bedrock topography map is shown on Figure Up-1.

The elevation of the bedrock within the basin ranges from over 500 m (a.s.l.) above the Niagara Escarpment to about 130 m (a.s.l.) along the basin's eastern boundaries. The Escarpment is a prominent topographic feature on the present land surface as well as on the buried bedrock surface. Below the Escarpment, the bedrock slopes eastward toward the Laurentian Valley, a regional bedrock valley that extends from Georgian Bay to Lake Ontario.

According to Sibul and Choo -Ying (1971), incised into the Escarpment is a deep bedrock valley, the trend of which approximates the overlying Hockley Valley. Three other significant bedrock channels occur along the Escarpment. All are thought to have been formed by fluvial or glaciofluvial erosion. The largest channel, of which only a remnant remains, is inferred to have extended between the Escarpment and the bedrock highs beneath Violet Hill and Sheldon Hill at elevations between 335 and 365 m (a.s.l.). The second channel is located near the northern end of the Escarpment where the valley floor is at an approximate elevation of 365 m (a.s.l.). The third channel is located between the exposed face of the Escarpment and the three small bedrock promontories immediately east of the Escarpment. The approximate elevation of the floor of this channel is 426 m (a.s.l.).

The oldest Palaeozoic rocks within the basin are the limestones of the Bobcaygeon Formation of the Simcoe Group (Figure Up-2). The formation which ranges in thickness from 7 to 87 m is of Middle Ordovician age. The Bobcaygeon Formation is overlain by the Verulam Formation which consists of limestones with interbeds of shales, 32 to 65 m thick. The youngest unit in the Simcoe Group sequence is the Lindsay Formation which has a thickness of 67 m and is comprised of two members. The lower member (unnamed) consists of limestones and the upper Collingwood Member consists of limestones and calcareous shales.

Overlying the Simcoe Group are the shales of Blue Mountain, Georgian Bay and

Queenston Formations of Upper Ordovician age. The Blue Mountain Formation consists of shales and has a maximum thickness of 60 m. The Georgian Bay Formation, with an average thickness of 100 m and a maximum thickness of 200 m, is comprised of shales with minor interbeds of siltstones and limestones. The youngest unit in the Upper Ordovician sequence is the Queenston Formation with a thickness ranging from 45 to 335 m. The unit consists of shales with interbeds of limestones and calcareous siltstones.

Overlying the Ordovician rocks are formations comprised mainly of dolostones, shales, limestones and sandstones of Lower Silurian age. These rocks are represented by the Cataract Group which includes the Whirlpool, Manitoulin, and Cabot Head Formations.

The Whirlpool Formation outcrops along the Niagara Escarpment and is comprised of up to 9 m of sandstones. The Manitoulin Formation outcrops along the Niagara Escarpment and occurs extensively in the subsurface of southwestern Ontario. It consists of dolostones with a maximum thickness of 25 m. The Cabot Head Formation occurs throughout southwestern Ontario and the Niagara Peninsula. It consists of 10 to 39 m of non-calcareous shales with minor calcareous sandstones, dolostones and limestones.

The youngest Palaeozoic rocks within the basin are the dolomites of the Amabel Formation of Middle Silurian age which extends from the Escarpment to the western boundaries of the basin. The dolomites are up to 38 m thick.

11.6 OVERBURDEN THICKNESS AND GEOLOGY

The overburden in the Upper Nottawasaga River basin consists of glacial, glaciofluvial, glaciolacustrine deposits of Pleistocene age with minor amounts of alluvial and swamp deposits of Recent age. The thickness of these deposits in the basin varies from 0 to 10 m over the Niagara Escarpment plateau to over 110 m along the eastern boundaries of the basin (Figure Up-3).

The surficial geology of the basin is shown on Figure Up-4 which is based on a map prepared by Sibul and Choo-Ying (1971). Three different tills have been identified within the basin, Tavistock Till, Newmarket Till, and kettleby Till (Thurston et al. 1992). Land forms of glacial deposits in the basin include drumlins, till plains, and end moraines.

The Tavistock Till is found within the basin over the Escarpment plateau. The till, which occurs as gently rolling ground moraine, was deposited by the Huron-Georgian Bay lobes during the Port Bruce Stadial. It is a strongly calcareous, silty clay to silt till between 2 to 12 m in thickness.

The Newmarket Till is found mainly as drumlinized till plains in the eastern part of the basin. The till, which ranges in thickness from 3 to 12 m, was deposited by the Simcoe Lobe during the later part of the Port Bruce Stade. It is a calcareous silt to sandy silt till.

The kettleby Till was deposited by an advance of the Simcoe Lobe during the Port Huron Stade. The till, which is about 2 m thick, occurs within the central parts of the basin to the north and west of Alliston and to the south and southwest of Beeton. The Kettleby Till is a highly calcareous silty clay to clay till.

Numerous drumlins occur exclusively east of the Escarpment and are associated with the Newmarket and Kettleby Tills. The drumlins are elongated hills with crests pointing northeast and tail ends pointing southwest and their cores are composed of silt to sand till.
Proglacial Outwash Deposits

Glaciofluvial ice-contact deposits in the form of kames are found in the basin just east of the Escarpment and in a few localities on top of the Escarpment. According to Sibul and Choo - Ying (1971), kame deposits also occur directly beneath the sand till. An example of such an occurrence is the gravel pit 4 km due south of Beeton where the kame is capped by about five feet of sand till.

Kame deposits consisting of sands and gravels, about 5 to 10 m thick, occur to the at the foot of the Niagara Escarpment at an elevation of about 425 m (a.s.l.) and north of Hockley at elevations between 300 and 325 m (a.s.l.). The deposits were formed by meltwater contained between the Escarpment and the ice.

Glaciofluvial outwash deposits of stratified sands and gravels occur at an elevation of about 305 m north of Thornton, near the southern boundary of the basin southeast of Hockley, and as narrow channels in the vicinity and above the Escarpment.

Glaciolacustrine sediments of clay, silt, and fine sands are found between Cookstown and Beeton. These sediments were deposited in ice-marginal lakes and ponds associated with glacial Lake Schomberg and subsequent phases of Lake Algonquin. Also, thick sequences of clay and silt directly underlie part of the till plains in the basin. Medium- to coarse-grained sands, and occasionally gravels of glaciolacustrine are found near the Innisfil Creek and along the lower part of the Nottawasaga River. Sibul and Choo-Ying (1971) note that as much as15 m of sand, interbedded with minor beds of silt and clay, can be seen in the banks of the Nottawasaga River.

Low, elongated ridges of stratified sand and gravel, formed in shallow-water lacustrine and fluvial environments, occur at an elevation of about 235 m (a.s.l.) on the outwash plain southwest of Alliston, and at an approximate elevation of 220 m (a.s.l.) on the Lake Algonquin sand plain due south of Alliston (Sibul and Choo-Ying 1971).

Recent alluvial deposits of clay, silt, and fine sand occur within the flood plains of various streams. Also, swamp organic deposits up to 1 m thick occur at the head of the Innisfil Creek and along the Bailey Creek in Tecumseth and Adjala Townships.

11.7 OCCURRENCE OF GROUNDWATER IN THE BEDROCK

As indicated earlier, only a small percentage of the wells within the basin are bedrock wells and the majority of these wells are located in the western part of the basin. With the exception of the Amabel Formation, all the other bedrock formations within the basin are of limited value as a source of groundwater supply.

The Simcoe Group is buried under a mantle of overburden deposits that range in thickness from 70 to over 110 m. For this reason, only a few wells have been drilled deep enough to penetrate the limestone formations of the Group which make it difficult to assess its hydrogeologic characteristics within the basin. Singer et al.(1997) calculated the transmissivity values for a sample of 6,414 wells constructed in the rocks of the Simcoe Group in southern Ontario. The geometric mean of the sample's transmissivity values was estimated to be 5.7 m^2/day and the water-yielding capability of the Simcoe Group was assessed to be fair.

According to Sibul and Choo-Ying (1971), the groundwater availability in the Blue Mountain, Georgian Bay and Queenston Formations within the basin is poor. In their study of the hydrogeology of southern Ontario, Singer et al.(1997) treated the Blue Mountain and Georgian Bay Formations as one hydrogeologic unit. About 2,130 wells have been identified within the unit. Of these, a sample of 1,293 wells was selected to determine the transmissivity distributions for the wells within the unit. The minimum and maximum transmissivity values were estimated to range between 0.06 and 1,194 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be about 3 m^2/day. Given the large number of wells in the sample, Singer et al.(1997) characterized the water-yielding capability of the Blue Mountain-Georgian Bay hydrogeologic unit as poor.

A sample of 2,505 wells was selected by Singer et al.(1997) to estimate the transmissivity distribution for wells completed in the Queenston Formation. The minimum and maximum transmissivity values were found to range from 0.08 to 4,357m^2/day, respectively. The geometric mean of the sample's transmissivity distribution was estimated to be about 3 m^2/day. Given the large number of wells in the sample, Singer et al.(1997) characterized the water-yielding capability of the Queenston hydrogeologic unit as poor.

Singer et al.(1997), noted that all the formations of the Cataract Group are buried under thick sequences of younger rocks. Therefore, from a hydrogeologic point of view, the Cataract Group hydrogeologic unit was characterized as being of limited significance as a source of groundwater.

According to Turner (1976), the Amabel, Lockport and Guelph Formations constitute a high-capacity aquifer in the Niagara Peninsula and in the area between Hamilton and Owen Sound. Sibul and Choo-Ying (1971) indicated that the most of the bedrock wells within the basin derive their water from the Amabel Formation. Average yields from this formation are in the order of 50 to 100 litres per minute. Two municipal wells at Shelburne have penetrated 13 and 18 m of dolomite, and each has an estimated theoretical yield of 0ver 3,000 litres per minute. According to Sibul and Choo-Ying (1971), most of the wells ending in the Amabel Formation are between 15 to 30 m deep, and the majority of the domestic wells penetrate 5 to 10 m of bedrock before obtaining adequate water for supplies. Deeper penetrations into the rock normally have the effect of increasing the yields.

Singer et al.(1997) selected a sample of 6,516 wells in southern Ontario to determine the transmissivity distribution for the Amabel Formation. The minimum and maximum transmissivity values were estimated to range between 0.07 and 7,548 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be about 15 m^2/day. Given the large number of wells in the sample, Singer et al.(1997) characterized the water-yielding capabilities of the Amabel Formation as being good.

Specific capacity data are available for 440 bedrock wells within the Upper Nottawasaga drainage basin. Of these, 189 wells have specific capacities less than 5 l/min/m (Figure Up-5), 163 wells have specific capacities between 5 and 25 l/min/l (Figure Up-6), 45 wells have specific capacities between 25 and 50 l/min/m (Figure Up-7), and 43 wells have specific capacities higher than 50 l/min/m (Figure Up-8). Based on the distribution of wells on Figure Up-8, it is possible to confirm that the majority of the high capacity wells in the basin are located within the Amabel Formation.

11.8 GROUNDWATER OCCURRENCE IN OVERBURDEN

The overburden thickness east of the Niagara Escarpment ranges from 30 m to over 110 m and one well in the eastern portion of the basin has penetrated more than 150 m of overburden before encountering limestone. As Sibul and Choo-Ying (1971) indicate that although the overburden composition is highly variable, the chances of locating water-bearing formations within the overburden are generally good because of its large thickness. Also, geologic data are sufficient to permit the grouping of significant water-bearing materials in the overburden into aquifer units.

Six overburden aquifer units have been identified by Sibul and Choo-Ying (Map 2743B -5, 1971) within the overburden in the basin, the Kame-Outwash Aquifer Complex, the Till Complex, the Lake Algonquin Sand Aquifer, the Thornton Sand Aquifer, the Alliston Sand Aquifer, and the Hockley Valley Aquifer.

The Kame-Outwash Aquifer Complex is located to the east of the Niagara Escarpment. According to Sibul and Choo-Ying (1971), the aquifer consists of surficial sand and gravel deposits. At most localities these deposits are thick, often 30 m or more in the kame areas and generally 9 to 12 m in most outwash areas. Most of the deposits are unconfined, and the depth to the water table varies according to topography. The specific capacities of wells in these surficial deposits are usually less than 5 l/min/m.

Sibul and Choo-Ying (1971) indicate that most tills in the basin are poorly permeable and form semi-confining layers where they overlie more permeable water-bearing deposits. However, some facies of sand till, as in the southern part of Tecumseth Township, are composed of fairly uniform-grained sand with very little fine-grained material. At such locations, groundwater production from the sand till is limited only by insufficient saturated thicknesses. Where this till is sufficiently thick, large-diameter wells can provide adequate quantities of fresh water for domestic uses.

According to Sibul and Choo-Ying (1971), fine- to medium-grained sand deposits of glacial Lake Algonquin occur below a surface elevation of 230 m and form an unconfined aquifer throughout the sand plain in the basin. The thickness of this surface sand is variable but reaches about 25 m in areas north of Alliston. Most wells indicate a thickness in the order of 12 m. The specific yields of most of the wells in the aquifer are about less than 5 l/min/m.

Sibul and Choo-Ying (1971) have delineated the Thornton Sand Aquifer under the till plain north of Cookstown. The aquifer consists of medium- to coarse-grained sands which are part of a thick sequence of confined lacustrine deposit of sand, silt, and clay in the area. The thickness of the sand varies from a few meters to at least 8 m. A similar sand formation, located in a lacustrine sequence near Fennell on Highway 11, may be an eastward extension of this deposit. Most wells have specific capacities of less than 5 l/min/m.

According to Sibul and Choo-Ying (1971), a deep, confined sand aquifer underlies most of the eastern portion of the basin where the bedrock elevation is generally less than 150 m. (a.s.l.). The sand seems to be part of a deep lacustrine formation that extends south towards Lake Ontario and north toward Georgian Bay. It is usually reported as medium- to coarse-grained and is often overlain by a "blue clay" deposit about 12 m thick, or by a thick deposit of silt and clay, some of which may be glacial till. The majority of domestic wells penetrate only a few meters of the sand formation, and hence, most of the well yields are small.

Sibul and Choo-Ying (1971) have delineated the Hockley Valley Aquifer within a bedrock valley underlying the Nottawasaga River in the region of Hockley Valley and its extension to the northeast. The aquifer consists of gravel up to 6 m thick. The extent of the gravel cannot be precisely defined and wells often encounter water-bearing sand before gravel in the valley.

Data related to short-term pumping tests is available for 1,380 overburden wells. The data indicate that 729 wells (52.8%) have specific capacities ranging from 1 to 5 l/min/m (Figure Up-9), 493 wells (35.7%) have specific capacities between 5 and 25 l/min/m

(Figure Up-10), 86 wells (6.2%) have specific capacities between 25 and 50 l/min/m (Figure Up-11), and the remaining 72 wells (5.3%) have specific capacities larger than 50 l/min/m (Figure Up-12).

11.9 SUGGESTED BEDROCK MONITORING AREAS

Figure Up-13 shows the locations of all the bedrock wells within the basin and the boundaries of suggested areas for monitoring of groundwater in the bedrock. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials above the bedrock (Figure Up-14).

Areas where groundwater in the bedrock is highly susceptible to contamination are defined as those where the bedrock is either near or at the surface or is covered by highly permeable sand and/or gravel deposits. Areas where the bedrock is moderately susceptible to contamination are defined as those where the overburden above the bedrock contains clay or clay till deposits that are less than 3 m in thickness. Areas where the bedrock has low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, Area (A) is proposed for groundwater monitoring within the bedrock and areas (B, C, D, and E) are optional. Groundwater susceptibility to contamination within Area (A) on Figure Up-13 is variable ranging from high to low, whereas it is low within the optional areas.

Area (A) is located in the western one third of the basin and it is underlain by the rocks of the Queenston Formation, Cataract Group, and the Amabel Formation. It should be noted that the majority of the high capacity wells are within the Amabel Formation in Area (A) and only a few high capacity wells are within the other areas.

Areas (B and C) are underlain by the Blue Mountain Formation and have low susceptibility to contamination. Area (B) is located along the southern topographic divide within the headwaters of the Baily and Keenansville Creeks, whereas Area (C) is located north of Highway 89 within the Boyne River watershed.

Areas (D and E) are underlain by the rocks of the Simcoe Group and also have low susceptibility to contamination. Area (D) is located within the Alliston area, whereas Area (E) is located within the Cookstown area.

11.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Up-15 shows the location of overburden wells with specific capacities of over 10 l/min/m, and the boundaries of suggested areas for groundwater monitoring. Groundwater within the suggested areas has a high, variable, or low susceptibility to contamination. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials (Figure Up-16).

Areas where the shallow overburden aquifers are highly susceptible to contamination are defined as those where sand and/or gravel deposits are either near or at the surface. Areas where shallow overburden aquifers are moderately susceptible to contamination are defined as those where the sand and/or gravel deposits are covered by clay or clay till deposits that are less than 3 m in thickness. Areas where the overburden aquifers have low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, four areas (F, G, H, and I) are proposed for monitoring groundwater within the overburden. The susceptibility of groundwater to contamination is high within areas (G and H), low within Area (I), and variable within Area (F).

Areas (F and G) are located between the southern topographic boundaries and the Sheldon Creek. They contain parts of the Kame-Outwash Aquifer Complex and the Hockley Valley Aquifer and are underlain mainly by glaciofluvial deposits.

Area (H) is located within the Alliston area and is underlain by parts of the Alliston Sand Aquifer and the Lake Algonquin Sand Aquifer. Area (I), on the other hand, is located in the northeast of the basin within the Thornton area and is underlain by till deposits. The area also covers parts of the Thornton Sand Aquifer.

11.11 HISTORICAL MONITORING WELLS

No historical monitoring wells were installed within the Nottawasaga drainage basin. According to Sibul and Choo-Ying (1971), however, a number of monitoring wells were used during the study of the groundwater resources of the Upper Nottawasaga basin. Some of these wells were equipped with automatic recorders and others were measured manually. The types and locations of these wells are as follows:

Well No. 260	An overburden well, 38.72 m deep, and ends in silt. The well is located close to the eastern topographic divide close to an unnamed tributary to Innisfil Creek and contains two piezometers. One piezometer within silt at depth of 12.20 m

	and the other within silt till at depth of 21.34 m.
Well No. 261	An overburden well, 10.37 m deep, ends in silt, and located to the northwest of well 260 close to the same unnamed tributary.
Well No. 262	An overburden well, 40.55 m deep, ends in sand, and located west of Cookstown and just north of Highway 89. The well contains two piezometers; one within silt at depth of 12.19 m and the within clay till at depth of 21.65 m.
Well No. 263	An overburden well, 14.02 m deep, ends in sand, and located west of the Nottawasaga River and east of Elmgrove.
Well No. 264	An overburden well, 34.45 m deep, ends in clay, and located close to the topographic divide east of Highway 15. The well contains two piezometers; one is within silt till at depth of 13.41 m and the other is within clay at depth of 22.87 m.
Well No. 265	An overburden well, 12.80 m deep, ends in sand, and located just to the south of the Nottawasaga River on Highway 15.
Well No. 266	An overburden well, 43.29 m deep, ends in silt till, and located at the intersection of Highways 7 and 15. The well contains three piezometers; the first is within clay at depth of 8.54 m, the second is within clay till at depth of 15.85 m, and the third is at depth of 24.69 m.

All the water level measurements in the above wells were done manually. Automatic recorders, however, were installed in the following two wells:

Alliston Observation Well	An overburden well, 5.78 m deep, ends in sand, and located northeast of Alliston on Highway 10.
Cookstown Observation Well	An overburden well, 12.20 m deep, ends in sand till, and located north of Cookstown on highway 27.

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FIGURES

Key Map - Up	A transparency to be used with other figures for orientation purposes.
Figure Up - 1	Bedrock topography in the Upper Nottawasaga drainage basin.
Figure Up - 2	Bedrock geology in the Upper Nottawasaga River drainage basin.
Figure Up - 3	Overburden thickness in the Upper Nottawasaga River drainage basin.
Figure Up - 4	Overburden geology in the Upper Nottawasaga River drainage basin.
Figure Up - 5	Bedrock wells with specific capacities equal to or less than 5 l/min/m.
Figure Up - 6	Bedrock wells with specific capacities between 5 and 25 l/min/m.
Figure Up - 7	Bedrock welis with specific capacities between 25 and 50 l/min/m.
Figure Up - 8	Bedrock wells with specific capacities higher than 50 l/min/m.
Figure Up - 9	Overburden wells with specific capacities equal to or less than 5 l/min/m.
Figure Up -10	Overburden wells with specific capacities between 5 and 25 l/min/m.
Figure Up -11	Overburden wells with specific capacities between 25 and 50 l/min/m.
Figure Up -12	Overburden wells with specific capacities higher than 50 l/min/m.
Figure Up -13	Suggested and optional areas for monitoring groundwater in the bedrock.
Figure Up -14	Panel diagram showing the geologic logs of all bedrock wells.

Figure Up -15 Suggested areas for monitoring groundwater in the overburden.

Figure Up -16 Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 10 l/min/m.

Historical observation wells

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
002	2	6602788	NIAGARA (WELLAND)	PORT COLBORNE CITY (HUMBERSTON	01	015	648250	4747880	17	9.7536	Bedrock	
005	5	2601523	HALDIMAND	NORTH CAYUGA TOWNSHIP		023	592880	4750400	17	38.1	Bedrock	1974 - 1976
007	7	5708713	SIMCOE	ESSA TOWNSHIP	03	030	589850	4907950	17	6.096	Overburden	1974 - 1980
013	13	4703374	OXFORD	WEST OXFORD TOWNSHIP	03	002	520380	4769520	17	22.86	Overburden	1975 - 1977
015	15	4105768	MIDDLESEX	LONDON CITY			481298	4764300	17	12.192	Overburden	
018	18	4903777	PEEL	BRAMPTON CITY			599220	4838300	17	9.144	Overburden	1974 - 1975
019	19	5002027	PERTH	STRATFORD CITY			502930	4802350	17	117.348	Bedrock	
020	20		YORK	NORTH YORK BOROUGH								
025	25		NORFOLK	SIMCOE TOWN			557500	4743800	17			
029	29	4103521	MIDDLESEX	WESTMINSTER TOWNSHIP		048	471660	4753160	17	29.5656	Bedrock	1974 - 1979
032	32	6503535	WATERLOO	WOOLWICH TOWNSHIP (ELMIRA)			535590	4827750	17	35.9664	Overburden	1975 - 1976
033	33	6503536	WATERLOO	WOOLWICH TOWNSHIP (ELMIRA)			535505	4827750	17	18.288	Overburden	1974 - 1980
034	34	6503537	WATERLOO	KITCHENER CITY			540478	4808540	17	112.776	Bedrock	1975 - 1978
035	35	6503538	WATERLOO	KITCHENER CITY			540482	4808508	17	59.7408	Bedrock	1975 - 1978
038	38	2803709	HALTON	MILTON TOWN (MILTON)			590675	4819275	17	3.6576	Overburden	
040	40	6900931	YORK	ETOBICOKE BOROUGH	01	013	616199	4835043	17	32.3088	Bedrock	
044	44	5000241	PERTH	BLANSHARD TOWNSHIP		011	474700	4795257	17	11.5824	Overburden	
045	45	5001877	PERTH	BLANSHARD TOWNSHIP		011	474275	4795450	17	10.9728	Overburden	1974 - 1980
046	46	1701297	DUFFERIN	EAST LUTHER TOWNSHIP	04	029	553920	4862120	17	10.668	Overburden	1975 - 1980
047	47	6704194	WELLINGTON	GUELPH CITY			559910	4823150	17	46.3296	Bedrock	
048	48	6704195	WELLINGTON	GUELPH CITY			560240	4822835	17	61.5696	Bedrock	
051	51	5002028	PERTH	FULLARTON TOWNSHIP		016	482780	4802210	17	5.4864	Overburden	
056	56	3404047	LAMBTON	FOREST TOWN			418540	4771920	17	33.528	Overburden	1974 - 1980
058	58	4701317	OXFORD	EAST ZORRA TOWNSHIP	10	011	515750	4780855	17	40.8432	Bedrock	
059	59	6503534	WATERLOO	KITCHENER CITY			539865	4810265	17	61.5696	Bedrock	1975 - 1978
064	64	2600272	HALDIMAND	NORTH CAYUGA TOWNSHIP		024	592905	4750805	17	30.48	Bedrock	1974 - 1980
065	65	4902206	PEEL	MISSISSAUGA CITY	03	013	609543	4820409	17	10.0584	Bedrock	1974 - 1978
069	69		PEEL	BRAMPTON CITY (TORONTO GORE)								
070	70		PEEL	BRAMPTON CITY (TORONTO GORE)								
071	71	4105766	MIDDLESEX	WESTMINSTER TOWNSHIP		062	478438	4747840	17	13.4112	Overburden	1974 - 1980
072	72	4103435	MIDDLESEX	LONDON CITY (WESTMINSTER)	02	018	484550	4753780	17	46.9392	Overburden	
073	73	4103442	MIDDLESEX	LONDON CITY (WESTMINSTER)	02	018	484310	4754120	17	67.056	Bedrock	
082	82	6500265	WATERLOO	KITCHENER CITY (WATERLOO TWP)			544590	4806630	17	39.624	Overburden	1974 - 1980
083	83	6500271	WATERLOO	KITCHENER CITY (WATERLOO TWP)			544590	4806860	17	36.576	Overburden	
086	86		MIDDLESEX	GLENCOE VILLAGE			441900	4732700	17			
087	87	6500127	WATERLOO	CAMBRIDGE CITY (GALT)			555732	4806601	17			1974 - 1975
090	90	6905098	YORK	NORTH YORK BOROUGH	01	016	626320	4845890	17	45.72	Overburden	1974 - 1980
091	91	4103839	MIDDLESEX	WESTMINSTER TOWNSHIP	08	015	484160	4745410	17	70.7136	Overburden	1974 - 1978

Historical observation wells

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
092	92	4102793	MIDDLESEX	NORTH DORCHESTER TOWNSHIP	01	002	488140	4762720	17	137.16	Bedrock	
093	93	4401179	NORFOLK	SIMCOE TOWN			556165	4742125	17	24.0792	Overburden	
094	94	4401182	NORFOLK	SIMCOE TOWN			556100	4742070	17	24.6888	Overburden	
095	95	4100477	MIDDLESEX	DELAWARE TOWNSHIP			466840	4753940	17	30.7848	Bedrock	1975 - 1976
096	96		MIDDLESEX	DELAWARE TOWNSHIP			466000	4752000	17			
097	97	4100498	MIDDLESEX	DELAWARE TOWNSHIP	02	001	467330	4753840	17	48.768	Overburden	
098	98	4100806	MIDDLESEX	LOBO TOWNSHIP	01	004	465530	4753440	17	33.2232		1975 - 1976
099	99	4105767	MIDDLESEX	LOBO TOWNSHIP	03	003	463360	4755158	17	4.572	Overburden	1975 - 1976
100	100	4106413	MIDDLESEX	LOBO TOWNSHIP	02	005	464840	4755200	17	6.7056	Overburden	1976 - 1980
101	101	4701407	OXFORD	EAST ZORRA TOWNSHIP	12	004	518865	4776805	17	18.5928	Bedrock	
102	102	4701406	OXFORD	EAST ZORRA TOWNSHIP	12	004	518865	4776800	17	18.5928	Bedrock	
103	103	4701426	OXFORD	EAST ZORRA TOWNSHIP	12	004	519140	4777235	17	15.8496	Bedrock	1974 - 1976
104	104	4701427	OXFORD	EAST ZORRA TOWNSHIP	12	004	519140	4777230	17	6.096	Bedrock	1974 - 1976
105	105	4100807	MIDDLESEX	LOBO TOWNSHIP	01	004	465300	4753260	17	31.0896	Bedrock	
106	106	6911674	YORK	MARKHAM TOWN (MARKHAM TWP)	03	006	632292	4854345	17	31.6992	Overburden	1974 - 1980
107	107	4100889	MIDDLESEX	LOBO TOWNSHIP	02	006	465180	4755140	17	39.624		1974 - 1980
108	108	5000099	PERTH	DOWNIE TOWNSHIP	14	001	493978	4789810	17	21.336	Bedrock	1974 - 1975
109	109		OXFORD	EAST ZORRA TOWNSHIP								
110	110		OXFORD	BLANDFORD TOWNSHIP			523000	4777000	17			
111..	111		OXFORD	BLANDFORD TOWNSHIP			522100	4777000	17			
111..	112		OXFORD	BLANDFORD TOWNSHIP			522100	4777000	17			
113	113	4100823	MIDDLESEX	LOBO TOWNSHIP	01	007	466940	4754580	17	24.6888	Overburden	
114	114	4103767	MIDDLESEX	WESTMINSTER TOWNSHIP	06	018	482140	4747800	17	62.7888	Overburden	1975 - 1975
115	115	1503757	OTTAWA-CARLETON	NEPEAN TOWNSHIP	01	005	431720	5021170	18	32.004	Bedrock	
116	116	6502124	WATERLOO	WILMOT TOWNSHIP		002	536325	4805375	17	29.5656	Overburden	1975 - 1978
117	117	6502168	WATERLOO	WILMOT TOWNSHIP		002	536875	4804000	17	41.4528	Overburden	1975 - 1978
118	118	5701892	SIMCOE	MIDLAND TOWN			587776	4954383	17	33.528	Overburden	
119	119	4900147	PEEL	CALEDON TOWN (ALBION)	03	014	596430	4858160	17	13.716	Overburden	
120	120		PEEL	BRAMPTON CITY (CHINGUACOUSY)								
121	121	1101581	ALGOMA	SAULT STE MARIE CITY			701680	5156850	16	25.6032	Bedrock	1975 - 1977
122	122	2905483	HASTINGS	THURLOW TOWNSHIP	06	022	313025	4905050	18	9.144	Overburden	1974 - 1980
123	123	2905484	HASTINGS	TYENDINAGA TOWNSHIP	06	007	317400	4911425	18	21.9456	Bedrock	1974 - 1977
124	124	1301823	BRANT	BRANTFORD TOWNSHIP	01	002	546800	4779250	17	9.7536	Overburden	1979 - 1980
125	125	6702767	WELLINGTON	PUSLINCH TOWNSHIP	10	005	567995	4822295	17	20.1168	Bedrock	
127	127	6702772	WELLINGTON	PUSLINCH TOWNSHIP	10	006	568302	4822098	17	37.1856	Bedrock	
128	128	6702765	WELLINGTON	PUSLINCH TOWNSHIP	10	005	567463	4821813	17	28.956	Bedrock	
129	129	6702763	WELLINGTON	PUSLINCH TOWNSHIP	10	004	566680	4821515	17	32.004	Bedrock	
130	130	6702808	WELLINGTON	PUSLINCH TOWNSHIP	11	004	567971	4823026	17	44.196	Bedrock	

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
131	131	6702809	WELLINGTON	PUSLINCH TOWNSHIP	10	004	568056	4822756	17	42.0624	Bedrock	1975 - 1980
132	132	1511863	OTTAWA-CARLETON	NEPEAN TOWNSHIP	02	005	432300	5019690	18	30.48	Bedrock	
133	133		OTTAWA-CARLETON	NEPEAN TOWNSHIP			440000	5014500	18			
134	134	1511857	OTTAWA-CARLETON	GLOUCESTER TOWNSHIP	02	015	455000	5031900	18	213.36	Bedrock	
135	135	1511856	OTTAWA-CARLETON	GLOUCESTER TOWNSHIP	01	021	451000	5032650	18	33.528	Overburden	
136..	136	4403135	NORFOLK	WINDHAM TOWNSHIP	05	007	548900	4755660	17	39.0144	Overburden	1974 - 1974
136..	137	4403134	NORFOLK	WINDHAM TOWNSHIP	05	007	548900	4755660	17	6.096	Overburden	
138	138	4401235	NORFOLK	SOUTH WALSINGHAM TOWNSHIP	04	013	540150	4722800	17	14.3256	Overburden	1974 - 1980
139..	139	4403178	NORFOLK	SOUTH WALSINGHAM TOWNSHIP			540160	4722790	17			1974 - 1975
139..	140	4401236	NORFOLK	SOUTH WALSINGHAM TOWNSHIP	04	013	540160	4722790	17	94.1832	Bedrock	1975 - 1976
141	141	3802198	NIAGARA (LINCOLN)	WEST LINCOLN TWP (CAISTOR)	01	017	606350	4766225	17	23.1648	Bedrock	
142	142		NIAGARA (LINCOLN)	ST.CATHERINES CITY (LOUTH)								
143	143	1903398	DURHAM	NEWCASTLE TOWN (CLARKE)	06	008	697900	4877800	17	3.6576	Overburden	
144	144	5710417	SIMCOE	ORILLIA TOWNSHIP	06	019	617440	4955550	17	3.6576	Overburden	
145	145		SIMCOE	MATCHEDASH TOWNSHIP			609200	4958000	17			
146	146	5710418	SIMCOE	TAY TOWNSHIP	08	009	600400	4953790	17	5.4864	Overburden	
147	147	6911675	YORK	KING TOWNSHIP	06	026	611140	4871150	17	2.7432	Overburden	
148	148	3802295	NIAGARA (LINCOLN)	WEST LINCOLN TWP (CAISTOR)	01	018	605570	4766480	17	18.8976	Bedrock	
149	149		YORK	EAST GWILLIMBURY TOWNSHIP			633000	4897500	17			
150	150		YORK	EAST GWILLIMBURY TOWNSHIP								
151	151		YORK	EAST GWILLIMBURY TOWNSHIP			635008	4888095	17			
152	152	1801493	DUNDAS	CHESTERVILLE VILLAGE			481720	4994390	18	15.5448	Bedrock	
153	153		RUSSELL	RUSSELL TOWNSHIP			472500	5011500	18			
154	154		PERSCOTT	SOUTH PLANTAGENET TOWNSHIP			505000	5024500	18			
155	155	1900663	DURHAM	NEWCASTLE TOWN (CLARKE)	01	019	697563	4865884	17	34.7472	Overburden	
156	156		HASTINGS	THURLOW TOWNSHIP			307000	4896000	18			
157	157	2905479	HASTINGS	HUNGERFORD TOWNSHIP	03	005	315650	4917925	18	4.2672	Overburden	1975 - 1975
158	158	2900519	HASTINGS	HUNGERFORD TOWNSHIP	02	005	315912	4915840	18	18.288	Bedrock	1975 - 1975
159	159	2900894	HASTINGS	HUNTINGDON TOWNSHIP	13	013	304324	4929056	18	7.62	Bedrock	
160	160		HASTINGS	THURLOW TOWNSHIP			308400	4907500	18			
161	161	2900238	HASTINGS	ELZEVIR & GRIMSTHORPE TOWNSHIP (	04	003	315160	4935201	18	10.9728	Bedrock	1975 - 1975
162	162	2905478	HASTINGS	MADOC TOWNSHIP	03	006	299500	4932200	18	4.8768	Overburden	1975 - 1975
163	163	2901047	HASTINGS	MADOC TOWNSHIP	03	006	299401	4932364	18	12.192	Bedrock	1975 - 1975
164	164	2102685	ESSEX	WINDSOR CITY (SANDWICH EAST)	03	095	337280	4680660	17	58.5216	Bedrock	1974 - 1980
165..	165	4701409	OXFORD	EAST ZORRA TOWNSHIP	12	003	518875	4776775	17	19.5072	Bedrock	1975 - 1977
165..	166	4701408	OXFORD	EAST ZORRA TOWNSHIP	12	003	518875	4776775	17	25.908	Bedrock	1975 - 1977
167	167	4901999	PEEL	BRAMPTON CITY (CHINGUACOUSY)	05	005	596155	4831702	17	6.096	Overburden	1974 - 1980
168	168	4901205	PEEL	BRAMPTON CITY (CHINGUACOUSY)	02	015	597059	4843937	17	40.2336	Bedrock	1974 - 1980

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
169	169	4901191	PEEL	BRAMPTON CITY (CHINGUACOUSY)	02	012	598455	4842174	17	29.2608	Overburden	
170	170	2101061	ESSEX	COLCHESTER SOUTH TOWNSHIP		015	342840	4654930	17	39.3192	Bedrock	1974 - 1980
171	171	2103851	ESSEX	COLCHESTER SOUTH TOWNSHIP		014	342649	4654902	17	11.2776	Overburden	
172	172	3300023	KENT	BOTHWELL TOWN			428050	4719550	17	10.668	Overburden	1974 - 1980
173..	173	1300721	BRANT	BURFORD TOWNSHIP	13	019	540025	4761350	17	9.7536	Overburden	1976 - 1977
173..	174	1301942	BRANT	BURFORD TOWNSHIP	13	019	540025	4761350	17	16.764	Overburden	
173..	175	1300722	BRANT	BURFORD TOWNSHIP	13	019	540025	4761350	17	24.384	Bedrock	
176..	176	4702077	OXFORD	SOUTH NORWICH TOWNSHIP	09	027	524100	4750750	17	9.7536	Overburden	1974 - 1978
176..	177	4702076	OXFORD	SOUTH NORWICH TOWNSHIP	09	027	524100	4750750	17	37.4904	Bedrock	1974 - 1980
178	178	5300976	PRINCE EDWARD	HALLOWELL TOWNSHIP	02	001	318540	4873068	18	30.48	Bedrock	
179	179		PRINCE EDWARD	HALLOWELL TOWNSHIP								
180	180		PRINCE EDWARD	HILLIER TOWNSHIP			300500	4869000	18			
181	181		PRINCE EDWARD	HILLIER TOWNSHIP			306000	4876000	18			
182	182	5001349	PERTH	STRATFORD CITY			503000	4802260	17	134.112	Bedrock	1974 - 1980
183	183	5200594	PERSCOTT	WEST HAWKESBURY TOWNSHIP	05	00[illegible]	528025	5042000	18	28.6512		1974 - 1977
184	184		PRINCE EDWARD	HILLIER TOWNSHIP			306500	4877000	18			
185	185	4703723	OXFORD	NORTH NORWICH TOWNSHIP	02	021	524670	4762460	17	7.0104	Overburden	
186	186	4703493	OXFORD	DEREHAM TOWNSHIP	11	014	516950	4746275	17	6.4008	Overburden	
187	187	2001946	ELGIN	BAYHAM TOWNSHIP	10	022	520550	4739750	17	5.1816	Overburden	1974 - 1975
188	188	5302490	PRINCE EDWARD	AMELIASBURG TOWNSHIP	02	075	306325	4883600	18	6.096	Overburden	
189	189	5302491	PRINCE EDWARD	HALLOWELL TOWNSHIP		003	318000	4865060	18	14.3256	Bedrock	
190	190	2503162	GREY	SULLIVAN TOWNSHIP	03	023	507910	4910800	17	26.8224		1974 - 1976
191..	191	2504249	GREY	SULLIVAN TOWNSHIP	03	023	507875	4910810	17	9.4488	Bedrock	1975 - 1977
191..	192	2504250	GREY	SULLIVAN TOWNSHIP	03	023	507875	4910810	17	16.764	Bedrock	1975 - 1977
191..	193	2504251	GREY	SULLIVAN TOWNSHIP	03	023	507875	4910810	17	25.908	Bedrock	1975 - 1977
194	194	2503164	GREY	SULLIVAN TOWNSHIP	03	023	507900	4910785	17	115.2144		1974 - 1980
195..	195	2504255	GREY	SULLIVAN TOWNSHIP	03	022	507935	4910840	17	113.0808		1975 - 1977
195..	196	2504254	GREY	SULLIVAN TOWNSHIP	03	022	507935	4910840	17	93.2688		1975 - 1977
195..	211	2504253	GREY	SULLIVAN TOWNSHIP	03	022	507935	4910840	17	73.152		1975 - 1977
195..	212	2504252	GREY	SULLIVAN TOWNSHIP	03	022	507935	4910840	17	38.7096		1975 - 1977
197..	197	2504256	GREY	SULLIVAN TOWNSHIP	03	023	508510	4910380	17	16.1544	Overburden	1975 - 1977
197..	198	2504257	GREY	SULLIVAN TOWNSHIP	03	023	508510	4910380	17	40.2336	Bedrock	1975 - 1977
197..	199	2504258	GREY	SULLIVAN TOWNSHIP	03	023	508510	4910380	17	49.6824	Bedrock	1975 - 1977
200..	200	2504259	GREY	SULLIVAN TOWNSHIP	03	023	507240	4910150	17	8.8392	Bedrock	1975 - 1977
200..	201	2504260	GREY	SULLIVAN TOWNSHIP	03	023	507240	4910150	17	14.3256	Bedrock	1975 - 1977
200..	202	2504261	GREY	SULLIVAN TOWNSHIP	03	023	507240	4910150	17	22.86	Bedrock	1975 - 1977
203..	203	2504262	GREY	SULLIVAN TOWNSHIP	03	022	507130	4911300	17	10.0584	Bedrock	1975 - 1977
203..	204	2504263	GREY	SULLIVAN TOWNSHIP	03	022	507130	4911300	17	14.9352	Bedrock	1975 - 1977

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
203..	205	2504264	GREY	SULLIVAN TOWNSHIP	03	022	507130	4911300	17	21.9456	Bedrock	1975 - 1977
206	206	4106020	MIDDLESEX	CARADOC TOWNSHIP	01	015	460740	4747920	17	6.7056	Overburden	1974 - 1980
207	207	3400030	LAMBTON	ALVINSTON VILLAGE			429160	4740965	17	23.4696		1974 - 1980
208	208	3100714	KENORA	UNSURVEYED			321100	5747350	16	31.3944	Bedrock	1974 - 1975
209	209	2900582	HASTINGS	HUNGERFORD TOWNSHIP	05	001	312982	4918717	18	21.6408	Bedrock	
210	210	2901189	HASTINGS	MADOC TOWNSHIP	10	001	309371	4932209	18	6.7056	Bedrock	1974 - 1974
213	213	6704351	WELLINGTON	PUSLINCH TOWNSHIP	10	004	567300	4822500	17	3.3528	Overburden	1976 - 1980
214	214	4900661	PEEL	CALEDON TOWN (CALEDON TWP)	05	008	587938	4858896	17	9.144	Overburden	1979 - 1980
217	217	3305579	KENT	CAMDEN TOWNSHIP	03	002	401725	4715000	17	45.72	Overburden	1974 - 1978
218	218	6700869	WELLINGTON	GUELPH CITY			558601	4823643	17	72.5424	Bedrock	
219	219	3305578	KENT	CAMDEN TOWNSHIP	03	002	401725	4715025	17	45.72	Overburden	1975 - 1976
221	221	4106416	MIDDLESEX	MOSA TOWNSHIP	02	013	440900	4723040	17	40.8432	Overburden	1974 - 1978
222	222	2100602	ESSEX	COLCHESTER SOUTH TOWNSHIP		054	343580	4650550	17	38.7096	Bedrock	1974 - 1980
223..	223	6602771	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	05	037	624885	4755430	17	41.148	Bedrock	
223..	224	6602772	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	05	037	624885	4755430	17	68.58	Bedrock	
223..	225	6602773	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	05	037	624885	4755430	17	80.772	Bedrock	
226..	226	6602774	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	05	037	624870	4755410	17	33.2232	Overburden	
226..	227	6602775	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	05	037	624870	4755410	17	53.34	Bedrock	
228	228	6602409	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	05	037	624850	4755430	17	53.34	Bedrock	1976 - 1980
230	230	2901104	HASTINGS	MADOC TOWNSHIP	05	028	297557	4946253	18	12.192	Bedrock	1974 - 1975
235	235	6100599	THUNDER BAY	RUPERT TOWNSHIP (UNSURVEYED)			494200	5576450	16	38.4048	Overburden	1974 - 1974
239	239	1601461	COCHRAN	UNSURVEYED			703350	5545050	16	35.9664	Overburden	1974 - 1974
240	240	6602582	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	05	037	624780	4755450	17	33.528	Bedrock	
241	241	5200776	PERSCOTT	L'ORIGNAL VILLAGE			523760	5051250	18	23.1648	Bedrock	1974 - 1974
245	245	6602920	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP			624840	4755750	17			
246	246	6602201	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	04	038	624507	4755313	17	38.1	Overburden	
247	247	6502371	WATERLOO	WILMOT TOWNSHIP		001	533925	4808600	17	36.8808	Overburden	1974 - 1975
249..	248	4904155	PEEL	CALEDON TOWN (ALBION)	05	023	593580	4864050	17	20.4216	Overburden	
249..	249	4904156	PEEL	CALEDON TOWN (ALBION)	05	023	593580	4864050	17	45.72	Overburden	
249..	250	4904157	PEEL	CALEDON TOWN (ALBION)	05	023	593580	4864050	17	85.9536	Bedrock	
251..	251	4904158	PEEL	CALEDON TOWN (ALBION)	06	023	594400	4864030	17	18.288	Overburden	1976 - 1977
251..	252	4904159	PEEL	CALEDON TOWN (ALBION)	06	023	594400	4864030	17	42.2816	Overburden	1976 - 1977
251..	253	4904160	PEEL	CALEDON TOWN (ALBION)	06	023	594400	4864030	17	66.4464	Overburden	1974 - 1980
256	256	2904367	HASTINGS	THURLOW TOWNSHIP	06	023	313250	4905130	18	57.912	Bedrock	1974 - 1977
257	257	5200394	PERSCOTT	PLANTAGENET VILLAGE			500550	5041250	18	10.668	Overburden	1974 - 1977
283	283		COCHRAN	LITTLE TOWNSHIP								
284	284		COCHRAN	MATHESON TOWNSHIP								
285	285		COCHRAN	BLACK RIVER-MATHESON TOWNSHIP (								

Historical observation wells

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
286	286		COCHRAN	SHAW TOWNSHIP								
287	287		COCHRAN	PINARD TOWNSHIP (UNSURVEYED)								
289	289		NIPISSING	AIRY TOWNSHIP			715700	5040800	17			
290	290		NIPISSING	SABINE TOWNSHIP								
291	291		RENFREW	RADCLIFFE TOWNSHIP								
292	292		HASTINGS	BANCROFT VILLAGE			273000	4995000	18			
293	293		HASTINGS	CARLOW TOWNSHIP			291800	5013000	18			
294	294		NIPISSING	SPROULE TOWNSHIP								
296	296		KENORA	EAR FALLS IMPROVEMENT DISTRICT (U								
297	297		KENORA	EAR FALLS IMPROVEMENT DISTRICT (U								
299	299		KENORA	EAR FALLS IMPROVEMENT DISTRICT (U								
300	300		KENORA	EAR FALLS IMPROVEMENT DISTRICT (U								
301	301	4605197	DURHAM	UXBRIDGE TOWNSHIP (UXBRIDGE)	04	001	648440	4871940	17	7.0104	Overburden	1974 - 1978
302	302	4605198	DURHAM	PICKERING TOWN	07	021	650270	4866780	17	6.096	Overburden	1974 - 1977
303	303	4605199	DURHAM	PICKERING TOWN	01	027	652040	4853850	17	13.4112	Overburden	1974 - 1976
304	304	4601666	DURHAM	PICKERING TOWN	07	019	650925	4867270	17	129.2352	Overburden	1974 - 1975
305	305	6910969	YORK	MARKHAM TOWN (MARKHAM TWP)	09	026	642220	4866260	17	6.096	Overburden	1974 - 1980
306	306	6910970	YORK	RICHMOND HILL TOWN (WHITCHURCH)	02	003	628000	4866850	17	6.4008	Overburden	
307	307	6903809	YORK	MARKHAM TOWN (MARKHAM TWP)	06	018	637016	4861257	17	12.8016	Overburden	
308	308	4605089	DURHAM	AJAX TOWN	04	013	655500	4862055	17	3.6576	Overburden	1974 - 1976
309	309	3305577	KENT	TILBURY EAST TOWNSHIP	04	009	386240	4683020	17	7.0104	Overburden	1974 - 1978
310	310	3100650	KENORA	UNSURVEYED			576600	5910600	15	28.0416	Bedrock	1974 - 1974
311	311	6100799	THUNDER BAY	EXTON TOWNSHIP (UNSURVEYED)			512400	5556500	16	8.2296	Overburden	
312	312	6100798	THUNDER BAY	EXTON TOWNSHIP (UNSURVEYED)			512450	5556500	16	28.6512	Overburden	
313	313	6100802	THUNDER BAY	EXTON TOWNSHIP (UNSURVEYED)			512480	5556500	16	14.0208	Overburden	
314	314	6100796	THUNDER BAY	EXTON TOWNSHIP (UNSURVEYED)			512500	5556500	16	28.6512	Overburden	
315	315	6100795	THUNDER BAY	EXTON TOWNSHIP (UNSURVEYED)			511400	5556100	16	7.62	Overburden	1974 - 1974
316	316	6100794	THUNDER BAY	EXTON TOWNSHIP (UNSURVEYED)			511410	5556110	16	28.956	Overburden	
317	317	6100793	THUNDER BAY	EXTON TOWNSHIP (UNSURVEYED)			511420	5556110	16	13.716	Overburden	
318	318	6100800	THUNDER BAY	EXTON TOWNSHIP (UNSURVEYED)			511600	5557000	16	8.2296	Overburden	
319	319	6100803	THUNDER BAY	EXTON TOWNSHIP (UNSURVEYED)			511610	5557000	16	20.7264	Overburden	1974 - 1975
320	320	6100792	THUNDER BAY	EXTON TOWNSHIP (UNSURVEYED)			511620	5557000	16	13.716	Overburden	
321	321	6100791	THUNDER BAY	NAKINA IMPROVEMENT DISTRICT (NAKI			521400	5560100	16	9.144	Overburden	
322	322	6100790	THUNDER BAY	NAKINA IMPROVEMENT DISTRICT (NAKI			521400	5560110	16	4.572	Overburden	
323	323	6100789	THUNDER BAY	NAKINA IMPROVEMENT DISTRICT (NAKI			520800	5561150	16	15.24	Overburden	
324	324	2905974	HASTINGS	HUNGERFORD TOWNSHIP	02	001	313510	4915850	18	17.0688	Bedrock	
324	325	2905975	HASTINGS	HUNGERFORD TOWNSHIP	02	001	313510	4915850	18	50.9016	Bedrock	
324	335	2904370	HASTINGS	HUNGERFORD TOWNSHIP	02	001	313510	4915850	18	59.436	Bedrock	

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
326	326	2904371	HASTINGS	HUNGERFORD TOWNSHIP	02	001	313520	4915850	18	13.716	Bedrock	1975 - 1975
327	327	2904369	HASTINGS	THURLOW TOWNSHIP	06	013	309250	4905630	18	56.388	Bedrock	1975 - 1975
328	328	2906070	HASTINGS	THURLOW TOWNSHIP			309117	4905783	18			1975 - 1978
329	329	4605090	DURHAM	PICKERING TOWN	07	011	653880	4869120	17	4.8768	Overburden	1974 - 1978
330..	330	4605544	DURHAM	PICKERING TOWN	07	012	653750	4869000	17	12.192	Overburden	1976 - 1976
330..	331	4605545	DURHAM	PICKERING TOWN	07	012	653750	4869000	17	22.2504	Overburden	1976 - 1976
332..	332	4605546	DURHAM	PICKERING TOWN	07	012	653650	4868950	17	47.8536	Overburden	1976 - 1976
332..	333	4605547	DURHAM	PICKERING TOWN	07	012	653650	4868950	17	72.5424	Overburden	1976 - 1976
334	334	3404143	LAMBTON	DAWN TOWNSHIP	02	024	400800	4728775	17	22.2504		
336	336	4605087	DURHAM	AJAX TOWN	04	013	655500	4862060	17	14.6304	Overburden	1976 - 1976
337	337	4605548	DURHAM	AJAX TOWN	04	013	655520	4862030	17	28.0416	Bedrock	1976 - 1976
338	338	6911580	YORK	WHITCHURCH-STOUFFVILLE TOWN (M	05	034	632400	4866650	17	10.9728	Overburden	
339	339	6910828	YORK	WHITCHURCH-STOUFFVILLE TOWN (M	05	034	632378	4866560	17	26.2128	Overburden	
340	340	6910965	YORK	WHITCHURCH-STOUFFVILLE TOWN (W	06	027	632050	4878700	17	8.8392	Overburden	1974 - 1980
341	341	6910966	YORK	KING TOWNSHIP	03	029	616150	4874450	17	17.0688	Overburden	1974 - 1974
342	342	6902665	YORK	KING TOWNSHIP	02	019	616510	4885132	17	92.964	Overburden	1974 - 1980
343	343	6910967	YORK	KING TOWNSHIP	03	009	615075	4880425	17	3.6576	Overburden	1974 - 1980
344	344	6910968	YORK	EAST GWILLIMBURY TOWNSHIP	01	121	621475	4889650	17	3.3528	Overburden	1974 - 1978
345	345	3302635	KENT	HARWICH TOWNSHIP	01	012	416740	4687800	17	49.0728	Bedrock	1975 - 1978
346..	346	3002701	HURON	MORRIS TOWNSHIP	08	027	476495	4840190	17	17.6784	Overburden	1975 - 1976
346..	347	3002702	HURON	MORRIS TOWNSHIP	08	027	476495	4840190	17	49.0728	Bedrock	1975 - 1976
346..	348	3002703	HURON	MORRIS TOWNSHIP	08	027	476495	4840190	17	128.6256	Bedrock	1975 - 1976
349..	349	3002704	HURON	MORRIS TOWNSHIP	08	026	476405	4840820	17	16.4592	Overburden	1975 - 1976
349..	351	3002706	HURON	MORRIS TOWNSHIP	08	026	476405	4840820	17	45.72	Bedrock	1974 - 1980
349..	352	3002707	HURON	MORRIS TOWNSHIP	08	026	476405	4840820	17	125.8824	Bedrock	1975 - 1976
350	350	3002705	HURON	MORRIS TOWNSHIP	08	026	476350	4840875	17	22.2504	Bedrock	1975 - 1976
353..	353	3002708	HURON	MORRIS TOWNSHIP	08	027	476880	4840550	17	15.24	Overburden	1975 - 1976
353..	354	3002709	HURON	MORRIS TOWNSHIP	08	027	476880	4840550	17	46.9392	Bedrock	1975 - 1976
353..	355	3002710	HURON	MORRIS TOWNSHIP	08	027	476880	4840550	17	84.1248	Bedrock	1975 - 1976
353..	376	3002711	HURON	MORRIS TOWNSHIP	08	027	476880	4840550	17	122.8344	Bedrock	1975 - 1976
356	356	3100176	KENORA	INDIAN RESERVE OSNABURGH 63B			693530	5675200	15	17.3736	Bedrock	
357	357	3100578	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			694210	5704000	15	7.9248	Overburden	
358	358	3100577	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			694200	5704000	15	12.4968	Overburden	
359	359	3100569	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			694400	5704400	15	12.4968	Overburden	
360	360	3100570	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			694600	5704250	15	12.192	Overburden	
361	361	3100571	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			694200	5704050	15	21.0312	Overburden	1974 - 1975
362..	362	3100572	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			695800	5707000	15	15.8496	Overburden	
362..	363	3100572	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			695800	5707000	15	15.8496	Overburden	

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
364..	364	3100573	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			695600	5707050	15	6.096	Overburden	
364..	365	3100573	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			695600	5707050	15	6.096	Overburden	1974 - 1975
366	366		KENORA	PONSFORD TOWNSHIP (UNSURVEYED)								
367	367	3100574	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			695600	5706900	15	12.192	Overburden	
368	368	3100575	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			694600	5704900	15	9.144		
369	369	3100576	KENORA	PONSFORD TOWNSHIP (UNSURVEYED)			694700	5704500	15	16.1544	Overburden	
370	370	3100713	KENORA	UNSURVEYED								
371	371	3306508	KENT	HOWARD TOWNSHIP	01	015	420620	4710280	17	21.6408	Overburden	1974 - 1980
372	372	4703490	OXFORD	BLENHEIM TOWNSHIP	10	008	537760	4792000	17	9.4488	Overburden	1974 - 1974
373	373	5709214	SIMCOE	WASAGA BEACH TOWN			578250	4931025	17	60.96	Overburden	1974 - 1980
374	374	2803707	HALTON	MILTON TOWN (MILTON)			591175	4818750	17	3.6576	Overburden	1974 - 1980
375	375	6403790	VICTORIA	WOODVILLE VILLAGE			660200	4917700	17	11.5824	Bedrock	
377	377	2804289	HALTON	HALTON HILLS TOWN (GEORGETOWN)			586240	4832900	17	33.2232	Overburden	1974 - 1980
383	383		HALTON	OAKVILLE TOWN								
384	384	6100951	THUNDER BAY	NAKINA IMPROVEMENT DISTRICT (NAKI			519050	5560900	16	8.5344	Overburden	
385	385	6100952	THUNDER BAY	NAKINA IMPROVEMENT DISTRICT (NAKI			519025	5560800	16	14.6304	Overburden	1974 - 1975
386	386	6100953	THUNDER BAY	NAKINA IMPROVEMENT DISTRICT (NAKI			518775	5560750	16	7.62	Overburden	
387	387	6100954	THUNDER BAY	NAKINA IMPROVEMENT DISTRICT (NAKI			519950	5561325	16	16.4592	Overburden	
388	388	6100955	THUNDER BAY	NAKINA IMPROVEMENT DISTRICT (NAKI			521350	5560225	16	11.8872	Overburden	
389	389	1601761	COCHRAN	MOOSE TOWNSHIP			525790	5681365	17	17.9832	Bedrock	
390	390	1601760	COCHRAN	MOOSE TOWNSHIP			526335	5681025	17	19.5072	Bedrock	
391	391	1601759	COCHRAN	MOOSE TOWNSHIP			526050	5681250	17	19.812	Bedrock	
392	392	1601758	COCHRAN	MOOSE TOWNSHIP			524835	5679775	17	19.812	Overburden	
393	393	1601757	COCHRAN	DYER TOWNSHIP (UNSURVEYED)			463000	5605200	17	32.004	Overburden	
394	394	6503795	WATERLOO	NORTH DUMFRIES TOWNSHIP	11	032	544080	4798800	17	10.0584	Overburden	1974 - 1974
395	395	6500679	WATERLOO	NORTH DUMFRIES TOWNSHIP	12	029	547950	4800000	17	15.24	Overburden	1974 - 1974
396	396	6502145	WATERLOO	WILMOT TOWNSHIP		011	530300	4804475	17	66.7512	Bedrock	1974 - 1980
397	397	6702699	WELLINGTON	PUSLINCH TOWNSHIP	09	004	566140	4821145	17	19.812	Bedrock	1974 - 1979
398	398	6911700	YORK	MARKHAM TOWN (MARKHAM TWP)	05	013	635261	4858632	17	29.5656	Overburden	1974 - 1979
399	399	3802296	NIAGARA (LINCOLN)	GRIMSBY TOWN (NORTH GRIMSBY)	05	012	614640	4779880	17	14.3256	Bedrock	1974 - 1980
400	400	2906088	HASTINGS	SIDNEY TOWNSHIP	05	001	291640	4896980	18	19.812	Bedrock	1974 - 1980
403	403		HALTON	OAKVILLE TOWN								
404	404		HALTON	OAKVILLE TOWN								
405	405	4605830	DURHAM	PICKERING TOWN	06	020	651608	4864396	17	80.772		1975 - 1980
406	406	4605833	DURHAM	PICKERING TOWN	08	024	646842	4868419	17	15.5448	Overburden	1975 - 1980
407..	407	4401229	NORFOLK	SOUTH WALSINGHAM TOWNSHIP	04	005	535300	4721000	17	96.9264	Bedrock	1974 - 1976
407..	408	4401230	NORFOLK	SOUTH WALSINGHAM TOWNSHIP	04	005	535300	4721000	17	7.9248	Overburden	1974 - 1979
409..	409	4400980	NORFOLK	NORTH WALSINGHAM TOWNSHIP	08	003	531560	4725225	17	25.908	Overburden	

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
409..	410	4400980	NORFOLK	NORTH WALSINGHAM TOWNSHIP	08	003	531560	4725225	17	25.908	Overburden	
409..	411	4400980	NORFOLK	NORTH WALSINGHAM TOWNSHIP	08	003	531560	4725225	17	25.908	Overburden	
412	412	4401018	NORFOLK	NORTH WALSINGHAM TOWNSHIP	10	008	533325	4728135	17	5.4864	Overburden	1974 - 1977
413	413	4400966	NORFOLK	MIDDLETON TOWNSHIP	04	023	533400	4738050	17	23.7744	Overburden	1974 - 1977
414	414	2800838	HALTON	HALTON HILLS TOWN (ESQUESING)	03	016	582887	4825889	17	11.5824	Bedrock	1974 - 1978
415	415	2802576	HALTON	MILTON TOWN (TRAFALGAR)	06	001	598956	4816824	17	15.24	Bedrock	1974 - 1977
416	416	2802691	HALTON	MILTON TOWN (TRAFALGAR)	09	011	597831	4824995	17	12.192	Overburden	
417..	417	2802629	HALTON	MILTON TOWN (TRAFALGAR)	07	006	598130	4821060	17	13.4112	Bedrock	
417..	418	2802629	HALTON	MILTON TOWN (TRAFALGAR)	07	006	598130	4821060	17	13.4112	Bedrock	
417..	419	2802629	HALTON	MILTON TOWN (TRAFALGAR)	07	006	598130	4821060	17	13.4112	Bedrock	
420..	420	2803355	HALTON	HALTON HILLS TOWN (ESQUESING)	03	011	585430	4824050	17	39.0144	Bedrock	
420..	421	2803355	HALTON	HALTON HILLS TOWN (ESQUESING)	03	011	585430	4824050	17	39.0144	Bedrock	
420..	422	2803355	HALTON	HALTON HILLS TOWN (ESQUESING)	03	011	585430	4824050	17	39.0144	Bedrock	
423..	423	2801195	HALTON	HALTON HILLS TOWN (ESQUESING)	08	002	593000	4825260	17	57.912	Bedrock	
423..	424	2801195	HALTON	HALTON HILLS TOWN (ESQUESING)	08	002	593000	4825260	17	57.912	Bedrock	
423..	425	2801195	HALTON	HALTON HILLS TOWN (ESQUESING)	08	002	593000	4825260	17	57.912	Bedrock	
426..	426	2803356	HALTON	HALTON HILLS TOWN (ESQUESING)	05	004	590300	4823700	17	29.8704	Bedrock	
426..	427	2803356	HALTON	HALTON HILLS TOWN (ESQUESING)	05	004	590300	4823700	17	29.8704	Bedrock	
426..	428	2803356	HALTON	HALTON HILLS TOWN (ESQUESING)	05	004	590300	4823700	17	29.8704	Bedrock	
429..	429	2803354	HALTON	HALTON HILLS TOWN (ESQUESING)	07	006	590580	4825580	17	29.2608	Bedrock	
429..	430	2803354	HALTON	HALTON HILLS TOWN (ESQUESING)	07	006	590580	4825580	17	29.2608	Bedrock	
429..	431	2803354	HALTON	HALTON HILLS TOWN (ESQUESING)	07	006	590580	4825580	17	29.2608	Bedrock	
432	432	6700628	WELLINGTON	ERIN TOWNSHIP	04	004	574829	4835386	17	32.004	Overburden	1974 - 1979
433..	433	6700627	WELLINGTON	ERIN TOWNSHIP	04	004	574813	4835461	17	51.5112		
433..	434	6700627	WELLINGTON	ERIN TOWNSHIP	04	004	574813	4835461	17	51.5112		
433..	435	6700627	WELLINGTON	ERIN TOWNSHIP	04	004	574813	4835461	17	51.5112		
433..	436	6700627	WELLINGTON	ERIN TOWNSHIP	04	004	574813	4835461	17	51.5112		
437	437	2800686	HALTON	HALTON HILLS TOWN (ESQUESING)	01	026	576768	4828028	17	15.24	Bedrock	1974 - 1980
438	438	2802097	HALTON	MILTON TOWN (NASSAGAWEYA)	07	031	573775	4829085	17	25.908	Bedrock	1974 - 1976
439	439	2801739	HALTON	MILTON TOWN (NASSAGAWEYA)	01	024	572137	4820541	17	15.5448	Overburden	1974 - 1976
440	440	6700542	WELLINGTON	ERAMOSA TOWNSHIP	05	001	571167	4827731	17	9.4488	Bedrock	1974 - 1976
441..	441	6700543	WELLINGTON	ERAMOSA TOWNSHIP	05	001	571184	4827740	17	15.5448	Bedrock	
441..	442	6700543	WELLINGTON	ERAMOSA TOWNSHIP	05	001	571184	4827740	17	15.5448	Bedrock	
443..	443	2801950	HALTON	MILTON TOWN (NASSAGAWEYA)	04	026	573854	4824214	17	17.6784	Bedrock	
443..	444	2801950	HALTON	MILTON TOWN (NASSAGAWEYA)	04	026	573854	4824214	17	17.6784	Bedrock	
443..	445	2801950	HALTON	MILTON TOWN (NASSAGAWEYA)	04	026	573854	4824214	17	17.6784	Bedrock	
443..	446	2801950	HALTON	MILTON TOWN (NASSAGAWEYA)	04	026	573854	4824214	17	17.6784	Bedrock	
443..	447	2801950	HALTON	MILTON TOWN (NASSAGAWEYA)	04	026	573854	4824214	17	17.6784	Bedrock	

Historical observation wells

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
448..	448	2803605	HALTON	OAKVILLE TOWN	01	015	604260	4813230	17	33.528	Bedrock	
448..	449	2803605	HALTON	OAKVILLE TOWN	01	015	604260	4813230	17	33.528	Bedrock	
450..	450	2803594	HALTON	OAKVILLE TOWN	02	005	606890	4816330	17	35.3568	Bedrock	
450..	451	2803594	HALTON	OAKVILLE TOWN	02	005	606890	4816330	17	35.3568	Bedrock	
452..	452	2803471	HALTON	OAKVILLE TOWN		005	609840	4813470	17	10.9728	Bedrock	
452..	453	2803471	HALTON	OAKVILLE TOWN		005	609840	4813470	17	10.9728	Bedrock	
454..	454	2803730	HALTON	OAKVILLE TOWN	01	023	601018	4812430	17	15.5448	Bedrock	
454..	455	2803730	HALTON	OAKVILLE TOWN	01	023	601018	4812430	17	15.5448	Bedrock	
456..	456	2803411	PEEL	MISSISSAUGA CITY (TRAFALGAR)	10	001	602340	4820830	17	39.624	Bedrock	
456..	457	2803411	PEEL	MISSISSAUGA CITY (TRAFALGAR)	10	001	602340	4820830	17	39.624	Bedrock	
456..	458	2803411	PEEL	MISSISSAUGA CITY (TRAFALGAR)	10	001	602340	4820830	17	39.624	Bedrock	
456..	459	2803411	PEEL	MISSISSAUGA CITY (TRAFALGAR)	10	001	602340	4820830	17	39.624	Bedrock	
456..	460	2803411	PEEL	MISSISSAUGA CITY (TRAFALGAR)	10	001	602340	4820830	17	39.624	Bedrock	
461..	461	2803412	PEEL	MISSISSAUGA CITY (TRAFALGAR)	10	002	601660	4821480	17	32.004	Bedrock	
461..	462	2803412	PEEL	MISSISSAUGA CITY (TRAFALGAR)	10	002	601660	4821480	17	32.004	Bedrock	
461..	463	2803412	PEEL	MISSISSAUGA CITY (TRAFALGAR)	10	002	601660	4821480	17	32.004	Bedrock	
464..	464	2803414	HALTON	MILTON TOWN (TRAFALGAR)	09	004	600960	4822140	17	21.336	Bedrock	
464..	465	2803414	HALTON	MILTON TOWN (TRAFALGAR)	09	004	600960	4822140	17	21.336	Bedrock	
466	466	2803410	HALTON	MILTON TOWN (TRAFALGAR)	03	007	593490	4816040	17	22.86	Bedrock	
467..	467	2803410	HALTON	MILTON TOWN (TRAFALGAR)	03	007	593490	4816040	17	22.86	Bedrock	
467..	468	2803410	HALTON	MILTON TOWN (TRAFALGAR)	03	007	593490	4816040	17	22.86	Bedrock	
469..	469	2803409	HALTON	MILTON TOWN (ESQUESING)	01	003	587150	4819060	17	29.8704	Bedrock	
469..	470	2803409	HALTON	MILTON TOWN (ESQUESING)	01	003	587150	4819060	17	29.8704	Bedrock	
469..	471	2803409	HALTON	MILTON TOWN (ESQUESING)	01	003	587150	4819060	17	29.8704	Bedrock	
472..	472	3701533	LENNOX & ADDINGT	NORTH FREDERICKSBURGH TOWNSHI	03	014	347450	4894450	18	57.6072	Bedrock	
472..	473	3701533	LENNOX & ADDINGT	NORTH FREDERICKSBURGH TOWNSHI	03	014	347450	4894450	18	57.6072	Bedrock	
474	474	3701191	LENNOX & ADDINGT	ERNESTOWN TOWNSHIP	05	014	355480	4902559	18	7.0104	Bedrock	1974 - 1978
475	475		LENNOX & ADDINGT	ERNESTOWN TOWNSHIP								
476	476		LENNOX & ADDINGT	ERNESTOWN TOWNSHIP								
477	477		LENNOX & ADDINGT	ERNESTOWN TOWNSHIP								
478	478	3700988	LENNOX & ADDINGT	ERNESTOWN TOWNSHIP	04	014	355863	4901601	18	31.6992	Bedrock	1974 - 1976
479	479	3701192	LENNOX & ADDINGT	ERNESTOWN TOWNSHIP	05	014	355459	4902602	18	13.4112	Bedrock	1974 - 1976
480..	480	3701193	LENNOX & ADDINGT	ERNESTOWN TOWNSHIP	05	014	355472	4902998	18	54.2544	Bedrock	
480..	481	3701193	LENNOX & ADDINGT	ERNESTOWN TOWNSHIP	05	014	355472	4902998	18	54.2544	Bedrock	
480..	482	3701193	LENNOX & ADDINGT	ERNESTOWN TOWNSHIP	05	014	355472	4902998	18	54.2544	Bedrock	
480..	483	3701193	LENNOX & ADDINGT	ERNESTOWN TOWNSHIP	05	014	355472	4902998	18	54.2544	Bedrock	
484	484	3701190	LENNOX & ADDINGT	ERNESTOWN TOWNSHIP	05	014	355378	4903167	18	23.7744	Bedrock	1974 - 1975
485..	485	2203604	FRONTENAC	PORTLAND TOWNSHIP	08	002	369637	4922214	18	24.6888	Bedrock	

Historical observation wells

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
485..	486	2203604	FRONTENAC	PORTLAND TOWNSHIP	08	002	369637	4922214	18	24.6888	Bedrock	
487	487	1901747	DURHAM	NEWCASTLE TOWN (DARLINGTON)	08	005	683492	4879563	17	25.908	Overburden	
488	488	1901748	DURHAM	NEWCASTLE TOWN (DARLINGTON)	08	005	683400	4879650	17	50.292	Overburden	
489..	489	1901484	DURHAM	NEWCASTLE TOWN (DARLINGTON)	04	006	685840	4870490	17	48.4632	Bedrock	
489..	490	1901484	DURHAM	NEWCASTLE TOWN (DARLINGTON)	04	006	685840	4870490	17	48.4632	Bedrock	
489..	491	1901484	DURHAM	NEWCASTLE TOWN (DARLINGTON)	04	006	685840	4870490	17	48.4632	Bedrock	
492	492	1901485	DURHAM	NEWCASTLE TOWN (DARLINGTON)	04	006	685840	4870450	17	12.8016	Overburden	
493	493	1901200	DURHAM	NEWCASTLE TOWN (DARLINGTON)	02	007	687015	4866169	17	9.7536	Bedrock	
494	494	1901201	DURHAM	NEWCASTLE TOWN (DARLINGTON)	02	007	687008	4866159	17	7.3152	Overburden	
495	495	1901671	DURHAM	NEWCASTLE TOWN (CLARKE)	05	035	688450	4871806	17	16.764	Overburden	
496..	496	1901052	DURHAM	NEWCASTLE TOWN (CLARKE)	08	031	687894	4878918	17	45.72	Overburden	
496..	497	1901053	DURHAM	NEWCASTLE TOWN (CLARKE)	08	031	687894	4878918	17	154.5336	Bedrock	
498	498	1900934	DURHAM	NEWCASTLE TOWN (CLARKE)	05	032	689207	4872204	17	65.2272	Bedrock	
499..	499	1900956	DURHAM	NEWCASTLE TOWN (CLARKE)	06	022	693114	4874233	17	46.3296	Overburden	
499..	500	1900956	DURHAM	NEWCASTLE TOWN (CLARKE)	06	022	693114	4874233	17	46.3296	Overburden	
499..	501	1900956	DURHAM	NEWCASTLE TOWN (CLARKE)	06	022	693114	4874233	17	46.3296	Overburden	
499..	507	1900957	DURHAM	NEWCASTLE TOWN (CLARKE)	06	022	693114	4874233	17	14.3256	Overburden	
502	502	1900733	DURHAM	NEWCASTLE TOWN (CLARKE)	02	032	691764	4865034	17	10.9728	Bedrock	
503..	503	1902685	DURHAM	NEWCASTLE TOWN (CLARKE)	10	028	687860	4881700	17	215.7984	Bedrock	
503..	504	1902685	DURHAM	NEWCASTLE TOWN (CLARKE)	10	028	687860	4881700	17	215.7984	Bedrock	
503..	505	1902685	DURHAM	NEWCASTLE TOWN (CLARKE)	10	028	687860	4881700	17	215.7984	Bedrock	
506	506	1902684	VICTORIA	MANVERS TOWNSHIP	01	006	687515	4881910	17	210.312	Bedrock	
508	508	1901783	DURHAM	NEWCASTLE TOWN (DARLINGTON)	09	021	676901	4878311	17	62.7888	Overburden	
509	509	1901733	DURHAM	NEWCASTLE TOWN (DARLINGTON)	07	021	678301	4874336	17	11.5824	Overburden	1979 - 1980
510..	510	1900044	DURHAM	BOWMANVILLE TOWN			685161	4865697	17	35.6616	Bedrock	
510..	511	1900044	DURHAM	BOWMANVILLE TOWN			685161	4865697	17	35.6616	Bedrock	
512	512	4606003	DURHAM	PICKERING TOWN	05	023	651820	4862274	17	82.6008		1975 - 1980
513	513	4103738	MIDDLESEX	WESTMINSTER TOWNSHIP	05	022	479040	4748890	17	43.8912	Overburden	1974 - 1980
514	514	6503056	WATERLOO	WILMOT TOWNSHIP		014	527650	4805550	17	15.5448	Overburden	1975 - 1980
515	515	1515480	OTTAWA-CARLETON	OSGOODE TOWNSHIP	08	021	464581	5009917	18	19.812	Bedrock	
516	516	5601895	RUSSELL	CLARENCE TOWNSHIP	05	028	489090	5026800	18	123.444	Bedrock	
517	517	1801967	DUNDAS	MATILDA TOWNSHIP	04	013	475100	4974750	18	50.292		
518	518	2403282	GRENVILLE	AUGUSTA TOWNSHIP	04	014	452850	4953520	18	38.1	Bedrock	
519	519	2301691	GLENGARRY	KENYON TOWNSHIP	21	006	508175	5021160	18	31.3944		
520	520	5801519	STORMONT	FINCH TOWNSHIP	06	023	496400	5005200	18	1.8288		1978 - 1978
521	521	5201152	PERSCOTT	SOUTH PLANTAGENET TOWNSHIP			499950	5027100	18			1978 - 1979
522	522	1801941	DUNDAS	CHESTERVILLE VILLAGE			481750	4994100	18	4.8768		1978 - 1980
523	523	2403219	GRENVILLE	EDWARDSBURGH TOWNSHIP	07	032	454500	4964400	18	9.4488		1978 - 1980

Historical observation wells

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
524	524	6504745	WATERLOO	WILMOT TOWNSHIP		015	527640	4804700	17	9.7536	Overburden	1975 - 1979
525	525	5601429	RUSSELL	RUSSELL TOWNSHIP	09	003	480740	5010960	18	14.3256	Overburden	
526	526	1902683	DURHAM	NEWCASTLE TOWN (CLARKE)	10	028	687880	4881670	17	122.8344	Overburden	1979 - 1980
527	527	6913678	YORK	GEORGINA TOWNSHIP (NORTH GWILLI	07	017	630200	4903450	17	3.9624	Overburden	1979 - 1980
528	528	6900491	YORK	EAST GWILLIMBURY TOWNSHIP	05	026	627793	4891631	17	4.2672	Overburden	1979 - 1980
529	529	5715034	SIMCOE	BARRIE CITY			605145	4912050	17	7.3152	Overburden	1977 - 1980
530	530	1901998	NORTHUMBERLAND	HOPE TOWNSHIP	03	026	707800	4870500	17	6.7056	Overburden	1977 - 1980
531	531	2805425	HALTON	BURLINGTON CITY	01	002	590760	4806960	17	19.812	Bedrock	1977 - 1980
532	532	6701127	WELLINGTON	GUELPH TOWNSHIP	05	008	563198	4825875	17	67.3608	Bedrock	1978 - 1980
533	533	6702925	WELLINGTON	WEST GARAFRAXA TOWNSHIP	04	006	554475	4843297	17	44.5008	Bedrock	
534	534	6502443	WATERLOO	WILMOT TOWNSHIP		018	525125	4805175	17	45.4152	Overburden	
535	535	6504435	WATERLOO	WOOLWICH TOWNSHIP (WATERLOO T		114	546109	4814347	17	12.192	Overburden	
536	536	6706084	WELLINGTON	NICHOL TOWNSHIP	11	016	544930	4837820	17	84.4296	Bedrock	1980 - 1980
537	537	6700956	WELLINGTON	GUELPH TOWNSHIP	01	011	555024	4820862	17	108.5088	Bedrock	1980 - 1980
538	538	6914591	YORK	KING TOWNSHIP	08	008	608400	4862675	17	6.7056	Overburden	1980 - 1980
539	539	6914592	YORK	VAUGHAN TOWN (VAUGHAN TWP)	09	017	609300	4851600	17	9.144	Overburden	1980 - 1980
540	540	6914593	YORK	KING TOWNSHIP	03	008	619610	4866430	17	9.144	Overburden	1980 - 1980
541	541	1514435	OTTAWA-CARLETON	NEPEAN TOWNSHIP	03	020	440515	5014864	18	89.6112	Bedrock	1978 - 1980
542	542	4704983	OXFORD	BLENHEIM TOWNSHIP			530512	4794851	17			1978 - 1980
543	543	4106709	MIDDLESEX	CARADOC TOWNSHIP	03	022	461148	4752335	17	28.6512	Overburden	1979 - 1980
544	544	6702440	WELLINGTON	GUELPH CITY (PUSLINCH TWP)	07	007	564663	4817366	17	82.6008	Bedrock	1977 - 1979
545	545	4404036	NORFOLK	TOWNSEND TOWNSHIP	11	021	567485	4750580	17	9.7536	Overburden	1978 - 1980
546	546	5602221	RUSSELL	CLARENCE TOWNSHIP	06	018	485700	5032220	18	44.8056	Bedrock	1978 - 1980
547	547	1801561	DUNDAS	WINCHESTER TOWNSHIP	06	001	470750	4992250	18	42.9768	Bedrock	1979 - 1979
548	548	6101092	THUNDER BAY	PAIPOONGE TOWNSHIP	01	012	318300	5359650	16	43.2816	Bedrock	1979 - 1980
549	549	3406612	LAMBTON	ENNISKILLEN TOWNSHIP	07	015	407640	4742665	17	5.4864	Overburden	1979 - 1980
550	550	5903822	SUDBURY	VALLEY EAST TOWNSHIP (HANMER)	03	002	502850	5167000	17	13.716	Overburden	1979 - 1980
551	551	6700832	WELLINGTON	ERIN VILLAGE			574476	4847451	17	21.9456	Bedrock	1979 - 1980
552	552	5714854	SIMCOE	VESPRA TOWNSHIP	07	025	601300	4913300	17	110.0328	Overburden	1979 - 1980
553	553	5109590	PETERBOROUGH	CAVAN TOWNSHIP	08	010	700745	4896285	17	7.9248	Overburden	1979 - 1980
554	554	2909393	HASTINGS	SIDNEY TOWNSHIP	05	013	296150	4898050	18	17.6784	Bedrock	1979 - 1980
555	555	1514800	OTTAWA-CARLETON	GLOUCESTER TOWNSHIP	05	028	455400	5015260	18	21.336	Bedrock	1979 - 1980
556	556	6301291	TIMISKAMING	ARMSTRONG TOWNSHIP	03	003	590870	5283200	17	49.0728	Bedrock	1980 - 1980
557	557	3900898	MANITOULIN	CARNARVON TOWNSHIP	11	021	409175	5057850	17	30.7848	Bedrock	
558	558	4900733	PEEL	CALEDON TOWN (CALEDON TWP)	01	006	584552	4851847	17	7.62	Overburden	
559	559	4905890	PEEL	CALEDON TOWN (CALEDON TWP)	06	027	570750	4855150	17	36.576	Overburden	
560	560	2602047	HALDIMAND	DUNN TOWNSHIP		013	613915	4748640	17	13.1064		
561	561	2602048	HALDIMAND	DUNN TOWNSHIP	09	009	612920	4748740	17	13.716		

Historical observation wells

Group No	Obs	Well_id	County	Township	Concession	Lot	Easting	Northing	UTM Zone	Well depth (m)	Well Type	Record Period
562	562	2602049	HALDIMAND	DUNN TOWNSHIP	09	009	615320	4748460	17	14.0208		
563	563	6602171	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	02	006	637902	4751798	17	14.9352	Bedrock	
564	564	6601622	NIAGARA (WELLAND)	PORT COLBORNE CITY			640444	4752074	17	8.2296	Overburden	
565	565	6810277	WENTWORTH	WEST FLAMBOROUGH TOWNSHIP	04	006	579900	4795520	17	6.4008		
567	567	6602168	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	02	005	638482	4749947	17	24.384	Bedrock	
568	568	6908519	YORK	AURORA TOWN			622680	4872440	17	99.06	Overburden	
569	569	6912092	YORK	AURORA TOWN (WHITCHURCH)	01	086	623647	4875368	17	99.06	Overburden	
570	570	6900693	YORK	NEWMARKET TOWN (EAST GWILLIMBU	01	096	621866	4879021	17	117.348	Overburden	
571	571	6904190	YORK	NEWMARKET TOWN			621911	4878390	17	137.16	Bedrock	
572	572	6602167	NIAGARA (WELLAND)	WAINFLEET TOWNSHIP	02	002	639923	4750766	17	12.8016	Bedrock	
573	573	5712847	SIMCOE	BARRIE CITY			604150	4915200	17	56.388	Overburden	
574	574	1702773	DUFFERIN	ORANGEVILLE TOWN	D	003	570877	4862442	17	24.0792		
575	575	6700932	WELLINGTON	GUELPH CITY (PUSLINCH TWP)			564690	4815545	17	82.296		
576	576	4202816	MUSKOKA	HUNTSVILLE TOWN (CHAFFEY)	04	032	645410	5026060	17	5.1816	Overburden	
577	577	4202817	MUSKOKA	LAKE OF BAYS TOWNSHIP (MCLEAN)	07	021	650000	5001540	17	2.4384	Overburden	
578	578	4202818	MUSKOKA	HUNTSVILLE TOWN (CHAFFEY)	04	032	645300	5026410	17	1.8288	Overburden	
579	579	4202819	MUSKOKA	HUNTSVILLE TOWN (CHAFFEY)	05	032	645430	5026650	17	1.2192	Overburden	
580	580	4202820	MUSKOKA	HUNTSVILLE TOWN (CHAFFEY)	04	032	645550	5026540	17	0.9144	Overburden	
581	581	4202821	MUSKOKA	HUNTSVILLE TOWN (CHAFFEY)	05	035	646490	5027200	17	0.9144	Overburden	
582	582	4202824	MUSKOKA									
585	585		WELLINGTON	PUSLINCH TOWNSHIP			566800	4810900	17			
VIB		4401260	NORFOLK	TOWNSEND TOWNSHIP	01	007	555250	4762620	17	28.3464	Bedrock	